IRON BRIDGES OF MODERATE SPAN

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IRON BRIDGES OF MODERATE SPAN

THEIR CONSTRUCTION AND ERECTION

BY

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PREFACE.

The Author of this little work having in his earlier professional days experienced much difficulty in acquiring really practical information on the details of constructive engineering in ironwork (finding, indeed, little or nothing said about it in books, and consequently having been compelled to rely altogether on his personal observation, and noting that even now engineering literature chiefly treats of abstractions, its pages being filled *ad nauseum* with letters, algebraic signs, equations, and formulæ) has attempted in the following pages to lay before the student, as well as before all others interested in the matter, the results of his own professional experience. He gives no abstractions; he deals merely with construction pure and simple, and all collateral matter incident to it.

In criticising specifications he simply draws the attention of engineers to points in them which he found, while acting as an inspector and responsible for their due fulfilment, to be defective, and to cause unnecessary friction and lack of harmonious feeling between the two parties to some of his contracts; while in other cases, where the specifications were what they should be, no such friction existed.

At the latter part of the last chapter will be found extracts which the author has taken the liberty of making

CONTENTS.

LIST OF ILLUSTRATIONS.

THE CONSTRUCTION AND ERECTION OF IRON BRIDGES.

CHAPTER I.

FIRST STEPS TAKEN—SELECTION OF SITE—PREPARATION OF DRAWINGS—FIGURED DIMENSIONS—UNPRACTICAL DRAWINGS—PACKING PIECES—SPECIFICATIONS—DRIFTING—OILING PLATES.

THE construction of an iron bridge, from its inception to its opening for public use, is effected by a regular and systematic routine of operations, and the intention of the author of this little volume is to describe in a simple and concise manner the method of their performance as well as to comment upon one or two points still debatable amongst engineers.

For convenience a road bridge, 140 feet span over a river, is assumed as the work to be carried out, and this will be quite sufficient to give a knowledge of principles such as apply to the construction of iron bridges of moderate span generally. The site for the bridge having been selected, the first step to be taken is to ascertain the nature of the subsoil on which the foundations of the abutments are to rest, and this is done by boring holes several feet deep into the ground at both banks, and, if central piers are being used, in the bottom of the river also. For whether the firm ground or base be near to or remote from the surface, it must be reached. In certain cases it may lie so deep that piles must be resorted to, but generally rock, London clay, or hard sand is come-at-able. The borings are frequently made, not by the engineer's regular staff, but by a

man who makes such work a special pursuit, having his own particular appliances for it. He sinks holes into the ground at each bank to a depth sufficient to reach hard and firm foundation, such as clay, hard sand, or, best of all, the solid rock. If the intention is to make the 140 feet in two spans, then borings are also made in the middle of the river to find foundations for the central pier; as the bridge selected is, however, to be of a single span, this requires no notice here.

When all questions of foundation are settled, the engineer proceeds to prepare two sets of drawings—one for the masonry, the other for the ironwork, as well as two specifications to correspond. The ironwork alone being the text of this book, no more need be said of the masonry. As has been observed in the preface, no calculations or formulæ are noticed for estimating strains; the student can refer to many excellent works on that topic. Drawings, however, require notice. In this high-speed age, when time to business men is of so much value, there exists a great temptation to unduly hurry the drawing office, with the result that details are often imperfectly worked out: rivets are shown in places where they cannot be put in actual construction, or they come just at joints; bolts are put in places on paper where their nuts cannot be got at with a spanner to turn them in practice, and various other defects and oversights occur, all of which cause delay at subsequent stages of the work. Drawings ought to be made to the largest convenient scale for general arrangements; and details should be as much as is possible full or half size, with lines not too fine, and to be distinctly coloured.

Some engineers object to give more than two views of a piece of work, such as elevation and plan, but no end elevation, sectional plan, &c. This is unwise; it irritates contractors and their managers and foremen, as they object to be put to trouble reading drawings more than is absolutely necessary, and they are tempted to assume certain things as being intended very different from the engineer's view.

Another thing engineers often forbid in preparing drawings, viz. dotted lines, alleging that they tend to complicate and obscure the drawings and confuse workmen. The author has certainly seen dotted lines that did so, for they were simply a series of strokes hastily ruled in without due regard to their object, and one of such short strokes coming in a particular place will show an angle-iron to have a division in it where really there should be none; and it may be all very well to say, "Oh, any person with an ounce of sense can see what is intended." That is quite a fallacy. The essence of good drawings is that they should be as perfect and distinct as the hand can make them, and dotted lines should be really dotted neatly and clearly, care being taken not to put dots at places where they will appear to apply to some other part of the work. All sections should have proper foot notes such as "Section on line A B, Fig. 3," and Fig. 3, &c., should have a section line put across it exactly at the proper place. This is sometimes not done; only the letters are put in, which is not sufficient. Colours ought to be used more generally than is too often the case at present; they give a great deal of clearness to the drawings, and in many cases enable the design to be read almost at a glance.

Another point of great importance is that the colouring for sections should be very distinct from that of elevations, and not only this, but a good draughtsman, with a little care, can always manage to alter his tints so as to bestow great distinctness on the individual parts of a structure, not resting content with washing on a blue here for wrought iron, or grey there for metal, but by an intelligent use of his colours make his drawings clear as print. For instance, a common method of distinguishing between iron in elevation and iron in section is either not to colour the former at all, or else in a pale tint, while the latter is washed in flat with a deep tint; but drawings may be made clearer still if sections are cross-hatched in colour with a brush, and where a number of parts, such as plates, &c., lie beside or

on each other, each ought to be hatched reverse to the other; while different parts near each other in elevation might be washed in tints of different depths, those farthest from the eye being deepest, and so on. It is more easy to make distinction in cast-iron parts than in those of wrought iron, because only blue can be used for the latter, while many shades of grey may be mixed for the former.

Another very important feature about working drawings is the use of figured dimensions. Engineers differ a good deal in opinion upon this, some of them considering that time spent figuring drawings, especially those of a large or full scale, is spent for nothing and wasted, while others agree with the author that full dimensions expedite subsequent operations and prevent mistakes and misunderstandings. Indeed, in most cases workmen cannot scale measurements off drawings unless they are mounted on boards. Not only should figured dimensions be put on, but they should be properly placed, and in nothing is the practical workshop knowledge of the draughtsman more required or displayed than here. A man either careless in his work or destitute of workshop or girder-yard experience, will crowd his drawings with a number of perfectly useless and confusing figures, rendering it often necessary for a foreman to work out many sums in addition and subtraction before he gets the size he wants. It is obviously impossible in a book to teach how drawings should be properly prepared for workmen; all a writer can do is to outline principles to be followed. Dimensions ought to be taken

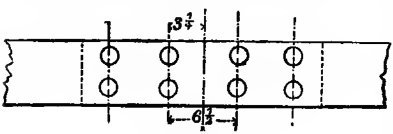


Fig. 1.

from and to planed or other cut faces or edges, and as far as possible each separate part in a general arrangement ought to have its own set of figures, so that a foreman can take a pencil tracing of any one piece with its dimensions and give it to a man to work to. Such a method as

is shown in sketch, Fig. 1, is bad, because in order to find distance of rivet-holes in right-hand plate from its edge a sum in subtraction must be worked, and obviously a tracing of right-hand plate alone could not be given to a workman without adding a dimension, which entails the return of the drawing to the office, because, in properly managed works, no dimensions should be put on drawings by foremen or workmen on any account; the drawing-office alone is the place for this.

The greatest care should be taken to make the arrow-heads at the extremities of the dimension lines as clear and well-defined as it is possible to make them. Often they are put on faintly, or so carelessly that the person working from the drawing is puzzled to know what is the real end of the line, whether it does or does not include some thin plate beyond, and more sums have to be worked to find it out. A draughtsman, if he is in doubt abou some practical point of method or possibility of construction, should never be too proud, if he is in the drawing-office of a works, to go to a foreman and ask him how best to arrange his details. There is no use in designing castings whose cores cannot be drawn or that cannot be moulded, nor in showing rivets so arranged that their snap ends are inside a box or other place, where a man may not have room to swing a hammer to close them down, while the heads are outside where there is ample room to do so.

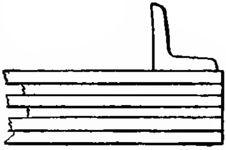


Fig. 2.

In bridge and girder work it constantly happens that angle-irons are fastened to plates, as shown in sketch, Fig. 2, the drawings showing the outer edge of angle brought out close to edge of plates, so as to be "flush." Now this looks all very nice and so forth on paper; in actual practice it never can be effected. Unless the rolls in which the angle-iron is finished are quite new and in first-rate order it will not be of perfectly uniform

breadth, and as the rolls are, when new, of the nominal size of the iron, of course the older they grow the more defective their grooves become, and the iron gets irregular in shape; the consequence is that it is not all along flush with the plates, but in some parts projects beyond them, making the work look unsightly, as shown in sketch, Fig. 3. The proper way is to place the angle-iron so that its outer edge will be at least $\frac{1}{8}$ inch inside plate edges, or even more. Again, in marking off plate and angle-iron butt joints and rivets, the designer ought to endeavour to avoid rivets falling just on joints, and necessitating half-holes; this often happens, and can be avoided by a little forethought, but where work is unduly hurried through the office points of this sort are neglected.

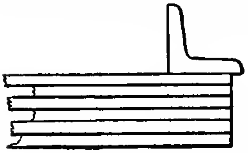


Fig. 3.

As to general common-sense principles to be observed in preparing designs for ironwork, care should be taken not to split hairs when estimating scantlings or sections of iron to be employed, but to work to such as can be readily purchased. No greater waste of time can be imagined than the calculation of sections to suit with absolute exactness the estimated strains to be borne, but which cannot be obtained. Here science gives place to absurdity.

In iron girders it often happens that packing pieces have to be introduced, and this is much to be regretted, as it is difficult to get workmen to shape or plane them with the requisite care to make them truly butt tightly where they are relied on to take compression strains, and in any but compression members they are nothing but redundant iron or idle dead weight. In the opinion of the author, if short pipes or thimbles used as "distance pieces," as shown in Fig. 4, were employed at B, riveting could be more firmly done and a great deal of dead weight got rid of. The sketch shows a series of main flanch plates with lattice ties and struts between them, the lattice ends being shown

in section. These thimbles could at least be used in tension work.

It is somewhat unfortunate that sufficient attention is not always given to details when preparing drawings and specifications, the result being that disputes and delay ensue during the progress of the work. Instances of this will be given where they present themselves in the course of this book.

The specification for any piece of work is equally important as the drawings. It usually consists of two parts, the one legal, and it is commonly a stereotyped form, not necessary to refer to here; the other the constructive part. This is really a sort of description of what the con-

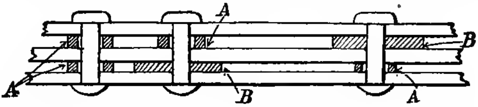


FIG. 4.

tractor must do, the quality and kind of materials he is to use, the men he is to employ, and the maximum time he is to take in completing the work. Too frequently specifications are very defectively drawn, and betray much of either ignorance or else inattention on the part of those preparing them. This is due to the practice of merely transcribing old specifications again and again, until they are nothing better than well-preserved fossils. The specifications of the earlier engineers were drawn when the details of practical construction were less understood by all parties and tools were less numerous and less perfect than is now the case, and too often specifications are ridiculed by contractors and works managers on account of clauses they contain; such an one for example as that "forbidding the use of drifting on any account whatever." This demand is absolutely impossible of fulfilment. As this little volume is intended more particularly for young men studying engineering, a drift, its use and abuse, must be

explained. There are three shapes of the tool, known respectively as the barrel drift, the taper drift, and the parallel drift. They are all short round pieces of the toughest and hardest steel. The barrel drift is shown at Fig. 5, and derives its name from its resemblance to a barrel in shape. It is usually about 6 to 8 inches in length and of various diameters (Fig. 5), according to the size of rivet holes being worked to. It is measured as a tool by its central or largest diameter, and tapers to about $\frac{3}{16}$ inch less at each end. Of the three shapes of drift it is the one most commonly used in bridge or heavy girder work, and its uses are twofold, namely to draw plates up to butt tightly to each other, and thus bring all the parts into their proper places, and in cases where, from inaccuracies of workmanship or other causes, the holes in one concentric line in a set of plates into which a rivet has to be put are too small to let the rivet freely in, the barrel drift, being first well greased, is driven, and as only just the central or largest part of the drift acts on the hole, the drift can be hammered right through and out at the other end, drawing in its course the plates more truly together, or, if the plates are already secured by other rivets, slightly enlarging the holes, say $\frac{1}{32}$ inch, or even less, but still quite sufficient to allow the rivet to be passed in. This last will not happen in good work. The taper drift (Fig. 6) is also used to draw up plates, and it, as its name indicates, is simply a round piece of steel drawn down by the smith to a slightly tapering form, say a taper of $\frac{1}{8}$ inch in four inches. It is used to draw plates together, or at least that is the idea of workmen. It is, however, both a mischievous and a really useless tool, because it fills up the hole in the first of a series or pile of plates, and as the holes in all are of equal diameter, it is clearly unable either

FIG. 5.

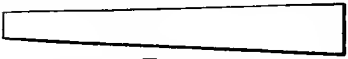


FIG. 6.

to draw all the plates till their rivet-holes are concentric, or to enlarge tight holes for rivets, as the barrel drift does. Fig. 6A shows this, as it represents in a slightly exaggerated manner the action of a taper drift, in a set of six plates to draw them true. It has passed, as will be seen, through the first plate, straining the hole open; through the second, and going partly through the third, whose hole it does not fill, and it fails altogether to reach the remaining plates. If specifications absolutely forbade the use of any but barrel or parallel drifts the clause would be reasonable and would inspire respect. Fig. 7 shows a parallel drift; it is simply a round bar of steel, having one end drawn down with a rather quick taper. It is most useful for drawing plates up into their proper position, because its small end can find its way into rivet-holes such as are shown in Fig. 6A, and as the diameter of the drift is the same throughout, save just at the entrance end, and equals that of the rivet-holes, it nicely draws the plates into a true position without straining or injuring the iron. In light girder work a tool such as Fig. 8 is used to draw the plates up; it is virtually a parallel drift with a spanner at one end; it is never struck with a hammer, and is simply used as a lever, but it is of little use in heavy work.

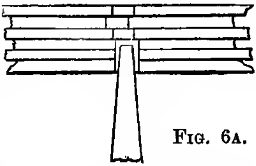


FIG. 6A.

FIG. 7.

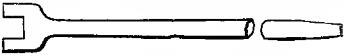


FIG. 8.

Another old-fashioned clause often retained still in specifications is the stipulation that the whole of the plates shall, after leaving the rolls, and while of a certain specified temperature, be dipped into oil. This is a most unpractical demand and is seldom or never carried out. No rolling mill is provided with an oil tank for the purpose, and

even if it were, the operation would entail not a little expense. If oil is insisted upon, then let a workman bring a bucket of oil and a coarse sweeping-brush and brush the oil over the hot plate. The idea suggesting the use of the oil is to prevent rust, but in fact it is not at all necessary, because the mill scale will effectually protect the plate; and besides this, most modern girder yards are to a great extent covered in against the weather, and so the plates are not exposed much to wet. In other respects this coating with oil is a positive evil. Workmen detest it, as it makes their clothes and hands dirtier and greasier than they already are, the plates are rendered slippery and dangerous either to walk on or to handle; and finally this greasy surface picks up a lot of dust and dirt, and when riveting time comes this is difficult and tedious to perfectly scrape off, while if not removed it is sandwiched between the plate faces and causes much difficulty in getting tight riveting.

CHAPTER II.

SPECIFIED TESTS FOR IRON—MODES OF TESTING—ELONGATION—BOARD OF TRADE REGULATIONS—EXAMINATION OF FRACTURE—AVERAGE OF A NUMBER OF TESTS—CUTTING PLATES FOR SAMPLES.

Another clause demands that iron from which rivets are to be made shall bear a certain tensile strain before breaking. This is an unwise stipulation, because, no matter how good the iron may be at first, it may be overheated when being made into rivets, and yet the engineer can hardly make any complaint, for he has passed the iron. By far the better plan is to stipulate that the rivets themselves shall bear cold bending under a hammer till the rivet is quite closed down on itself without cracking. This is quite a fair demand, because rivets of this quality can be readily purchased.

A very common item in a specification is that defining the testing of the iron to be supplied. The clause is usually a simple demand that the iron shall sustain a tensile strain of not less than 21 or 22 tons per square inch of section, according to the disposition of the engineer who designs the work, while it must also have a certain amount of elongation before fracture. Sometimes this is to be as much as 14 per cent.; other engineers are content with 13 or even 12 per cent. The reason for the two tests of breaking strength and elongation is that hard crystalline irons are those which, other things being equal, give the highest breaking strains; when they do fail, however, they give no notice and are therefore considered treacherous, and soft tough iron, while leaving a relatively lower co-efficient of breaking strength, elongates considerably before giving way, and therefore giving plenty of notice. The experienced

engineer then seeks a medium, and requires an iron which, while capable of sustaining an amply sufficient breaking strain, yet also, by a sensible elongation before fracture, gives indication of a reasonable toughness. Beside the reason given above there is another why a tough fibrous quality should be present in the iron. The natural tendency of iron, even at rest, is to become by degrees hard and crystalline, and if subjected to vibration the same process goes on more rapidly. So much so indeed, that a bar of the softest and toughest iron, really as tough as copper and extremely fibrous, will, if exposed to repeated blows from a moderately heavy hammer, actually become so crystalline and brittle as to separate into two pieces; and the engineering student cannot do better than read Fairbairn's "Useful Information for Engineers," where, as well as in other works by the same and other eminent authorities, he will find accounts of experiments on the effect of vibration upon iron and steel.

The iron is tested as follows. The millowner having contracted with the maker of the bridge to supply the whole of the iron at a certain price, sends in some sample plates, tees, and angles. The engineer, having received notice that the iron is ready for testing, either goes in person or sends a competent representative to the yard. He selects certain pieces, and stamping them with a steel stamp of his own, these pieces are then planed and filed to a proper shape for testing, and so as to be exactly one square inch in cross section. Fig. 9 shows the shape of a test piece ready to put into the machine. The size varies a little according to the habit of the inspecting engineer. Some engineers make the distance from A to B ten inches, and they thus get a measure of tenths, whereby

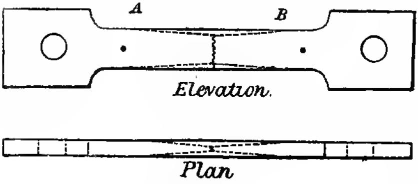


FIG. 9.

they can readily estimate the percentage of elongation. Others adopt $6\frac{1}{4}$ inches as the length, and it is one very convenient, being just one hundred-sixteenths of an inch, and consequently each one-sixteenth elongation represents one per cent.; therefore the percentage can be seen at a glance. The tees and angles are tested in the same way, the central web of the tee and one web of the angle-iron being planed and the remainder shaped as before described. The test sample, as shown in Fig. 9, is planed and filed between A and B perfectly parallel. It ought, on the contractor's behalf, to be carefully examined before testing, to see that no cracks, cuts, or indentations are on the part between A and B, as any such would injure the piece and cause it to break at a lower strain than it otherwise would. It must be also parallel and of exactly equal cross area. Before it is put into the testing machine, two marks are made with a centre-punch at A and B, Fig. 9, at an exact distance of $6\frac{1}{4}$ inches, or one hundred-sixteenths apart. The piece is then put into the testing machine, which consists of a system of levers and weights, to which one end of test piece is connected, and a hydraulic ram, to which the other end is secured. The machine is then loaded, to begin with, to a strain of say fifteen tons. It must be explained that the cross section of a test piece is not square except when the plate of which it was a part happens to be an inch thick. The plates in bridges such as those under notice are usually either $\frac{5}{8}$ inch or $\frac{3}{4}$ inch thick, and as there are 64 square eighths in a square inch, it follows that a $\frac{5}{8}$ test piece must be of a breadth found by dividing 5 into 64, or 12·8 eighths, or practically the piece must be $1\frac{19}{32}$ wide.

Starting, then, with fifteen tons, the loads are gradually increased, very great care being taken to avoid jerks or shocks of all kinds, because they are very destructive in their operation, and their true strain value cannot be measured in cases of this sort. They must be carefully excluded, and the loads so gradually applied as to give the

molecules of the iron time to adjust themselves to sustain the added strain.

At first little elongation is observable, but when the strain comes within two or three tons of the breaking or, as it is called, the ultimate stress, the iron stretches more rapidly, and finally breaks. The pieces are then taken out and the fractured ends examined, to ascertain what relative proportions exist of crystalline and fibrous iron respectively in the piece. The millowner, as has been already explained, has to supply an iron combining toughness with strength, and he piles tough iron with hard crystalline strong iron, and rolling the pile out again and again gets the class of material required. The same end can also be attained by other processes of manufacture.

With respect to testing the iron for such public structures as bridges, whether for road or rail, no legal restrictions exist, save that the Board of Trade demands that no part of an iron railroad structure shall be exposed to a strain exceeding five tons per square inch section in tensile work, nor more than four for compression. As to cast iron, it is never exposed to tension, and its compressive strength is so great no rule seems to exist about it; indeed, of late years it is falling gradually into desuetude, save for columns as a building material. The well-known engineer, Mr. Kirkaldy, selected the testing of iron and steel as a special professional pursuit, and spent a large sum of money in erecting a testing-house and fitting it with elaborate machinery, and for several years it has been the custom of many engineers to stipulate in their specifications that the iron required shall be tested by him. This, however, contractors object to, arguing that they are thus placed in the hands of one man, over whom they have no check, and who, although honest in intention, is, like all men, fallible and liable to be mistaken; and that resorting to him causes about a fortnight's delay in the work, and moreover, costs money, for of course the contractor has to pay all testing expenses. Contractors themselves, or their

millowners, as a rule, either have testing machinery of their own or can use that of friends of theirs; while, of course, all of them can put up a sheer-legs in their yards and test the iron by the simple method of attaching a scale platform to the suspended test piece, and loading it with pigs of cast-iron till it is broken. Certainly, when carefully done, this is a sufficient test, but it is also a clumsy, tedious method, and one leaving many openings for errors to creep in. The simplest plan is to use any really good testing machine made by a well-known firm. The iron may be tested in presence of both engineer and contractor, and thus disputes can be avoided; but any rough-and-ready, old, neglected, or otherwise unreliable machine, should not be used, no matter how strongly the contractor or millowner may urge its employment.

It is beyond the scope of this little work to go extensively into the testing of iron, a subject which is fully treated of by such able men as Fairbairn, Reed, and Kirkaldy.

To return to our test piece. When taken out of the machine and its fracture examined, its parts are laid on a level surface and joined back as closely as possible; a pair of compasses are then applied and the distance now existing between the centre-punch marks carefully measured. Suppose they are now 7 inches apart, evidently the piece has elongated twelve-sixteenths of an inch; hence the elongation is 12 per cent. It is usual to take three test pieces from the delivery of iron, and this raises a much disputed point as between engineers and contractors. It is obvious that in so skilled and difficult an art, one also depending so largely on questions of chemistry, as that of iron making, it is nearly impossible to get absolute uniformity in the results of any series of even three tests. The consequence is that owing to careless drawing of specifications, and a contempt for detail sometimes shown by men otherwise eminent, disputes arise as to whether, if one or two of the tests fall below the standard contracted for and one exceeds, causing

the *average* to reach the standard, whether the engineer can legally or fairly reject the whole delivery. Of course it is clear that no misunderstanding can arise if the test clause of the specification is drawn, say, as follows:—"The iron shall bear a tensile strain of not less than 22 tons per square inch of breaking section before fracture, and shall show an elongation of not less than 14 per cent. after fracture. No sample tested to fall below this standard. Averages of a number of tests will not be accepted."

Undoubtedly this would be a severe clause, and would if the specification had on its title-page a statement that its clauses would under no circumstances be relaxed in any point, increase the price tendered; while if no such statement was made upon the title, then the contractor would call upon the engineer and ask him did he mean to exact that clause absolutely before sending in his tender; for it may fairly be assumed that if every test shall be up equal to standard, it will be equivalent to demanding iron that will on an average of tests show 23 tons of strength. Here is an example of the evil of loosely drawn specifications, for the question as to whether the average of a set of tests or the lowest of the set is to be taken frequently forms cause of disputes.

The method of obtaining the test samples, too, should be very exactly specified, because as the plates and bars are of course all delivered of finished or nearly finished sizes, therefore if test pieces are cut from them they are spoiled, even in moderate-sized plates. This is always expensive, but becomes much more so with large plates, and contractors very often oppose any demand on the part of the engineer to cut samples from them. It may be said that a certain number of plates ought to be rolled so much in excess of the finished size as to leave a margin for taking test pieces, but the objection to this on the part of the engineer is that if the contractor choose to be dishonest, or the millowner either, they may roll these particular plates of a quality equal to bearing the tests, while all the rest

may be more or less inferior, thus rendering the system of testing a mere sham. One simple method of settling the matter is to take testing pieces out of the trimmings sheared from the plates when they come from the rolls, the engineer or his representative being present and stamping the plates and the samples; but still there is the objection that as the engineer cannot reside at the mill and see every piece rolled, of course if he attend but once or twice and secure samples, he has no guarantee that all the iron will be of equal quality, and therefore it is obviously better for all parties that the ordinary clause empowering the engineer to take test pieces whenever he pleases should be drawn distinctly, and stating that plates of any size may be cut, and this should be adhered to. Engineers and contractors are alike to blame in nearly all cases of disputes about the meaning of the various clauses of a specification: the engineer because he does not well define what he wants, and the contractor because before signing his contract he does not inquire the exact meaning of vague requirements. And all specifications should be the most common-sense documents possible, and ought to have on the title-page the words printed, "The whole of the terms of this specification will be rigidly exacted." Engineers in too many cases have weakly relaxed their specifications, and as a consequence contractors have got into the habit, when tendering, of estimating that they may safely discount some of the clauses as not likely to be insisted upon.

CHAPTER III.

MAIN GIRDERS, THEIR GENERAL DESIGN—SETTING OUT WORK—DRILLING—MARKING CENTRES OF HOLES—BENDING ROLLS—FLOORING—CAMBER OF MAIN GIRDERS—MODES OF MEASURING IT.

It may now be assumed that the iron has been tested and accepted, and the construction of the bridge can be proceeded with. The first thing the contractor does is to make copies of the working drawings on cloth—that is, on linen prepared with turpentine—so that tracings can be made upon it; these are fully dimensioned, and sent out to the foremen of the different workshops. The method of subsequent work varies somewhat in different yards, but we will describe one to begin with.

The most important parts of any iron bridge are what are called the main girders; these span the river or road, and sustain the cross girders and iron floor or platform of the bridge; these are either arched more or less vertically, or are straight, according to circumstances, and if arched and of moderate span are sometimes made of cast iron, in which case they are cast in lengths of from 15 to 20 feet, and are bolted together at their ends. A number of these are laid at equal distances of from 4 to 6 feet apart, sufficient to give the required width of roadway. It is, however, with wrought-iron bridges we propose to deal, and select a straight lattice girder bridge. Small lattice girders have but a single set of lattices between the top and the

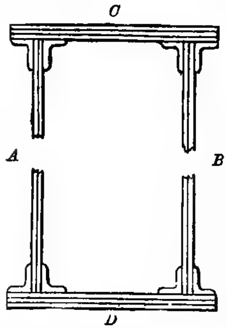


Fig. 10.

bottom flanges. Girders of any magnitude, such as for the kind of bridge under notice, have a double set, as shown in Fig. 10, where A and B show the arrangement of the two sets. The lattice bars are secured to the main flanges by angle-irons if the girders are small, but for road bridges or other heavy work they are fitted as shown in Fig. 11, wherein either one or two deep plates C and D are secured to main flanges. The sketch shows just a piece of main bottom flange, sufficient to illustrate the connection. A is the compression lattice, or strut, as it is sometimes designated; it is usually made either of angle or channel iron, and stiffened still more by cross lattice bars between each pair of struts to resist bending or buckling; while B is the tension lattice or tie. The compression lattices are always put inside, for convenience of cross bracing. Packing pieces are put in between the lattices and the side plates C and D wherever the lattices do not cross each other, and it is in places of this kind that the author considers thimbles should be substituted for packing pieces.

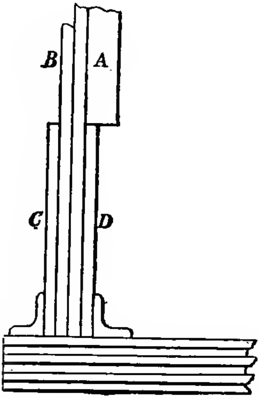


FIG. 11.

Instead of lattices, girders have plain web plates in some cases, and are then distinctly known as box girders, being indeed simply iron boxes. The finest examples of box girders is to be found in the Britannia bridge over the Menai Straits; and if, as is now usual, plain plate flanges are used, such girders are simple to make and are very strong. They are, however, heavy, and the sides offer much resistance to the wind. Scientifically regarded, they and lattice girders are alike, lattice girders being nothing more than plate web girders with holes cut in the web. There is more work required in constructing lattice girders, but

the parts are lighter and more portable than is the case with large plate girders.

Before any of the parts of the girder are planed or drilled, half a length of it is marked out full size, either upon a mould loft floor or else on a number of surface plates arranged upon a long series of trestles. In effect a full-sized drawing is very exactly and carefully made on these, and the precise position of each joint and rivet hole is marked. The several plates are then consecutively marked and are planed on all their edges accurately smooth and square. They are supplied from the mill according to specification, which demands that they shall be perfectly smooth, true, level, and free from all cracks, flaws, laminations, or other blemishes; all, therefore, they require is planing on their edges. There are various ways of effecting this. Special machines, also, are made for doing the work; but, perhaps, the best and cheapest method is that of piling a number of them on the bed of an ordinary planing machine and cramping them there very carefully and firmly. Both sides of the pile can be planed at the same time, and all the plates can thus be made absolutely identical in width. The ends must be planed by a different machine, because no planing-machine has a bed sufficiently wide to take plates 18 or 20 feet long. When the plates are planed they are ready for drilling; and here again the method of work varies. It has been already observed that specifications demand that all the parts shall be drilled while in the position they will finally occupy in the bridge. So far as the mere drilling of the main plates is concerned this can be done, and in yards fitted with a travelling drill it is done. The plates are piled just as a complete main flange and strongly secured between the rails on which the drill carriage moves. The drills are set in the machine at the proper distance apart; usually the rivets are pitched 4 inches from centre to centre, and so the drills are set. A series of centre-punch marks, 4-inch pitch, are made, on top plates, and the drill is set to work, drilling a complete set of holes

at one operation across the plates; then the drill is advanced forward 4 inches and begins again. Attention must be given by the foreman as well as by the engineer's inspector to this, because it occasionally happens that one or other of the drills become damaged, and if not at once replaced by a perfect one its chain of holes are necessarily defective.

Another method of putting the rivet holes in plates is to drill one plate very accurately, then it is cramped down successively on each of the others and a centre-punch, consisting of a round piece of steel turned to fit the rivet holes very accurately, and having one end turned down to a blunt point, same as is shown in sketch, Fig. 12, is taken, and with it all the positions of the holes in the other plates are marked. When marked the holes may be drilled at once out of the solid plate, or else the plates are taken to the punching machine. Into this machine a punch is fixed, one-eighth of an inch smaller than the finished rivet hole; it has also a little projection at its end centre. The punching machine is so made that the attendant can, by moving a little tumbler, cause the punch to be driven through the plate, or else it may just drop down upon it only. The plate is suspended in the loop of a chain hung from a little carriage running freely upon the jib or arm of a light crane. A labourer or two manipulate and shift the plate to the orders of the puncher, who adjusts it till the punch drops its projection in the punch mark on the plate; he then throws over the tumbler, and at the next stroke the punch is driven through the plate. The plate, when the punch is withdrawn, is then shifted, and the punch put out of gear till it is once more centred, when it is again put in operation, and so on till all the holes are punched. The plates are then taken to the drilling machine and drilled out $\frac{1}{8}$ inch larger than before, which makes them the full size, namely, $\frac{15}{16}$ inch diameter for $\frac{7}{8}$-inch rivets, for it is a rule to make the holes $\frac{1}{16}$ inch larger than the rivet for all rivets be-

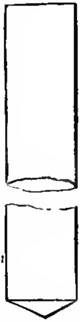


Fig. 12.

tween $\frac{5}{8}$ inch diameter and 1 inch ditto. This is necessary owing to the expansion of the rivet when hot, its having a little scale on it, defective concentricity of the various holes through which it must pass, and such like practical considerations. The use of drilling out the holes after punching is, that a circle of iron round the hole is injured by the punch, which when going through the iron tends to drag the immediately adjacent parts with a rending or tearing action. The nature of the action can be observed by the student if he take a common cotton reel and a round penholder. The reel with its central hole represents the die of the punching machine, while the penholder, which should just fit the hole easily, represents the punch. Now, if a piece of paper be laid over the hole, and the penholder be pressed down, it will be found to tend to push the paper into the hole before piercing it. In the early days of engineering it was supposed that the iron between a pair of rivet holes, say 3 inches apart, was injured, but more recent investigations throw doubt upon this, and it is now generally assumed that holes punched are surrounded with a narrow ring of injured iron only, and that this if drilled out will leave the plate in as good a condition as if the holes were drilled *ab initio*. This explains the reason for the method of drilling after punching. The relative economy of first punching and then drilling, as against drilling out of the solid, is a debatable matter, and depends upon other circumstances affecting the work in hand.

Where a travelling multiple drill is not at hand, then when a plate has been marked off it is cramped on top of a convenient number of others, and the drill run right through all of them.

As to angle-irons, they generally need to be straightened perfectly before being drilled, and this is done easily and quickly in a machine made for the purpose, consisting of two headstocks capable of being set nearer to or farther from each other, while facing the gap between them is a heavy block moved from and pushed towards them by an

excentric or a rotating shaft. When the bar requiring to be straightened is put in the machine the moving block does not itself reach it, but the attendant introduces a wedge-shaped piece of iron between bar and block, and the block then encounters it and forces it against the bar, which is of course deflected. The man begins with the small end of the wedge, and puts in a wider and wider part till he finds, by means of a string or straightedge, that the bar is truly straight. If plates chance to be bent a little they are straightened, paradoxical though it may seem, in a bending-rolls. They are a set of three rolls, arranged as shown in sketch, Fig. 13, the upper one being capable of adjustment up or down. If the upper roll is set low then any plate passed between them will be bent in proportion to the setting of the rolls, or else can be straightened, as may be required.

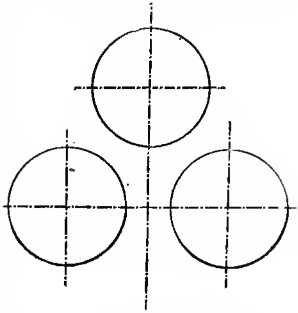


Fig. 13.

We come now to the flooring of the bridge. In the earlier days of ironwork of this sort, arches of brick, set with cement, were built between the cross girders, and were known technically as Jack arches. These were then made level above with ballast, to constitute a road bed. About thirty years ago, however, Mr. Robert Mallet conceived the idea of bending iron plates in a press into a shape like sketch, Fig. 14

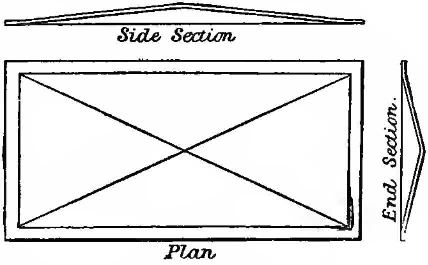


Fig. 14.

and they then became as capable as the brick arch to sustain loads. These plates were riveted to T-iron bars laid over and riveted to the cross girders. These plates became known as Mallet's buckled plates, and were and still are extensively used, being superior to brick arches in many ways. They are cheaper, can be completed to constitute a floor more rapidly, and make the difference between the road surface and the river surface less by some inches; often a most important point. A simple form of buckling is shown at Fig. 15, where the plate is simply bent slightly into an arch; this is cheaper and almost as strong as the form shown in Fig. 14, with the conspicuous advantage that a press need not necessarily be used, as the plates may be, and often are, bent in rolls such as are shown in Fig. 13, the flat margins being formed by striking the projecting part of the plate with a heavy mallet, which, as these plates, at least in such bridges as that under notice, seldom exceed $\frac{3}{8}$ inch thick, can be readily effected. The arch of the plate is laid either lengthways of the bridge, or occasionally crosswise, according to circumstances. Their ends are not planed, but are brought as close butt as possible, and the joint is overlaid with a joint-cover strip 5 inches wide, which is riveted to both plates. Fig. 16 shows the end view of a pair of plates laid down as flooring. These plates of course vary in size, but usually are 3 feet from edge to edge after bending, and are 10 feet long.

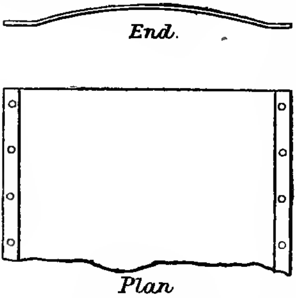


Fig. 15.

When these plates are bent in a press they are heated to a low red heat first, and after bending are set aside to cool. The inspecting engineer should take care to ascertain that all the plates have exactly the same camber, or that the

versed sine of the curve to which they are bent is alike. Usually it is 3 inches in a plate 3 feet wide. If the press when a plate is in it is not worked right up, so as to close the plate tightly between the die plates in all cases, the plates will not be level and flush when put down. More than this, care must be taken not to put down the heated plates where some parts will be wet and others dry, as this, by causing unequal contraction, will tend to warp them out of true shape, which will not only prevent their being flush, but will also prevent them bedding level on the tee-irons. When bent merely to an arch, if good plates, they will not need to be heated before bending, therefore, if truly bent at first, they will remain so. The cover strips are bent in the rolls even as the plates have been, with the

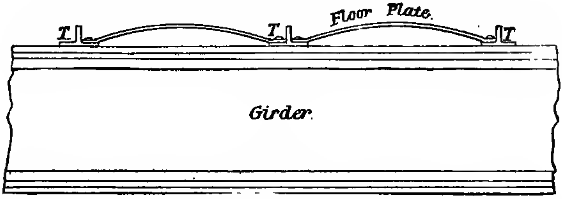


FIG. 10.

difference, of course, that the inner curve of the strip must be equal in radius to the outer curve of the plate, so that one may lie close to the other.

All the rivet holes in flooring plates and cover strips are punched, and are of greater pitch or distance apart than the riveting of the girders, the latter being 4 inches, while 6 inches is sufficient for the former; ⅝-inch rivets, too, are large enough. A well-made floor should lay down close and level, just as fast as the labourers can carry on the plates and put them down. No time is lost looking for numbered plates; they are all, or should be, alike. On the other hand, a badly made floor gives immense trouble, and causes fully six times as much expense as if the floor had been properly prepared in the first instance. In nothing more than in this is the folly of penny wisdom exemplified.

It is usual to stipulate in a specification for home work, that at least one of the main girders shall be put together in the contractor's yard before any of it is sent away. The object of this is to enable the engineer or his inspector to see how the work goes together, and allows of defects being discovered and amended where all the means for doing so are at hand. Of course no riveting is done, the parts are simply bolted together ready for riveting. In ordinary bridge work both main girders are alike, and therefore it may be reasonably assumed that if one is right in the yard both will be right at the place of final erection; therefore but one is erected in the yard, all the plates are carefully and deeply marked with numbers from the drawings, or when put together, and by these they are finally put together at the site, one of the duties of the yard foreman being to see that the marking is properly done.

Although later on it is the author's intention to say something about the duties of an inspector of ironwork, it may be as well here to direct attention to one very important point, namely, what is known as the camber of the main girders. This is a slight upward curve present in the girder when the entire bridge is completed. In a bridge of 150 feet span this camber would be from 2 to 3 inches: that is to say, the under surface of the centre of the girder would be 3 inches higher than either end. This is done with a twofold object; first, because however carefully a girder may be built, it is almost sure to settle a little as time goes on, and this allows it without having the girder lower in the centre than at the ends, which would look very unsightly.

It has been already said that all the parts of the girder have been marked out before they are drilled or cut, and they are so marked as that when put together the girder will have this camber. Care, however, is necessary in putting the parts together to bring the camber true, and when the inspector visits the yard to examine it he must bestow particular care on this. The curve is so slight that

it is barely noticeable to the eye, and a closer test must be applied. The girder consists of a top and a bottom member, boom or main flange. As the depth of the girder is usually from one-tenth to one-twelfth of the span, the reader will perceive that a very trifling alteration or inaccuracy in the camber of the bottom flanges will put the top one very much out of fit, and although the joints and rivet holes below seemed all close, butt and concentric respectively, yet those above might be all the very reverse, and an inexperienced inspector would fancy that this was due to bad workmanship, whereas the adjusting and "truing" of the camber below would bring everything right. Two kinds of error of camber may exist, the one being too much or too little, the other a want of uniformity, as instead of being a true curve it would be more or less serpentine.

The bottom flange is laid down upon a series of wooden blocks, which are supposed to be carefully set to rather more than the required camber—rather more, because for one thing they are sure to settle under the weight of the

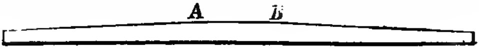


FIG. 17.

girder, and for another it is necessary, in order to allow the top plates to be got into their places; a little subsequent easing of the blocks lowers the girder, reduces the camber, and brings the top parts close.

The truth of the camber, which is measured on the bottom of the girder, can be determined by either of three different methods. The best and most scientific of these is to gauge it by means of a telescope or Dumpy level. Next to that it may be done by a straightedge and spirit-level in the following manner: a deep bar or plank of wood an inch thick at least, 6 inches deep at the centre, and about 4 inches at each end, having all the taper at one side, as shown in Fig. 17, is required; about 2 feet at its centre between A and B is to be perfectly parallel with the other

edge, which must be planed perfectly straight. The bar must not be less than 10 feet long. A good spirit-level, such as carpenters sometimes use, or such as is used in fitting-shops, is also requisite; it must be perfectly true. This is readily ascertained by putting it on any plane surface already known to be truly level, and first putting it down one way, observe where the bubble stands, which should be at the centre of the glass, then turn the level end for end and again observe it. If the bubble remain exactly in the same place, the level is reliable; if not it is worthless till it is adjusted, which can only be done by an instrument maker.

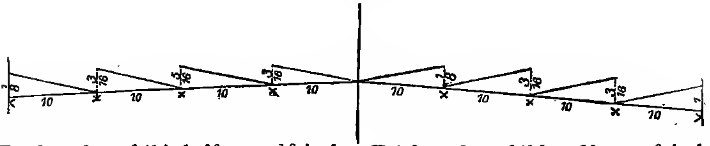
The mode of testing the camber with these is as follows—the precise centre of the girder must be first found by measurement and marked with chalk; then the bottom flange must be looked over to find the most convenient way of applying the straightedge. Generally the upper surface of the bottom flange, just outside the main angle iron is the best place, that is if the flange plate project at all beyond the angle; as this is rare, however, the straightedge must either be used along the centre of the girder between the two sets of lattices, or else along the main angle iron.

Starting from the centre chalk mark, one end of the straightedge is to be laid on the girder, the other end is then to be wedged up until the spirit-level shows it true. The distance between the wedged end of the straightedge and the iron is to be carefully measured and the place chalked. The straightedge is then carried on till its back end is brought to this mark, when it is rested upon the iron, and its other extremity again wedged up till it is level, this raising is also marked and measured, and so on to the end of the girder. Returning now to the centre, the same measurements are made from it to the other end of the girder. The inspector has his note-book, and making a sketch of the curve, he divides the line into as many lengths as there are measurements on the girder, and at each mark

he notes the measurement of the raised end of straight-edge. Fig. 18 shows the method exactly as it would appear in the note-book.

An inspection of the figures here shows that the camber of the whole span is the mean between $\frac{3}{4}$ and $\frac{13}{16}$. The curve also, though not mathematically true, is as fairly so as can reasonably be expected in such work.

If, upon examining his figures, the engineer or clerk of works finds serious errors of camber, his best course will be to plot the defective curve on paper to as large a scale as convenient, according to the figures, inking it say in black.



Total camber of this half span, $\frac{13}{16}$ inch. $\frac{1}{8} + \frac{3}{16} + \frac{5}{16} + \frac{3}{16} = \frac{13}{16}$.

Total camber of this half span, $\frac{3}{4}$ inch. $\frac{1}{4} + \frac{3}{16} + \frac{3}{16} + \frac{1}{8} = \frac{3}{4}$.

FIG. 18.

Then let him plot a true curve—an arc of a circle is usually that adopted—over the other, inking in red or blue. The places of error in the black line will at once appear, and if this drawing be taken on the works the foreman can be instructed what wedges to slack, letting the girder down, and where to apply a hydraulic jack to lift it up and drive in the wedges. The lowering should be exact to the measure required, but the lifting ought to exceed it a little, thus allowing for re-settlement. It is at this stage that the necessity for great accuracy of setting out, planing, and drilling, becomes apparent. If these operations have been badly done the various parts can never be made to fit correctly, and though, on the other hand, they have been properly performed, careless erection will spoil all.

A simple method of ascertaining exactly the amount of camber in the girder as a whole, is by means of three cross staffs, such as are used by road surveyors for getting short levels, dips, or rises. These staffs are coarse wooden

crosses like tee-squares, one of them being about three inches longer than the others (see Fig. 19), where D is the short and C E F the long staff. The part cross-chequered on E F is made white with chalk, and is the portion in excess of length beyond D.

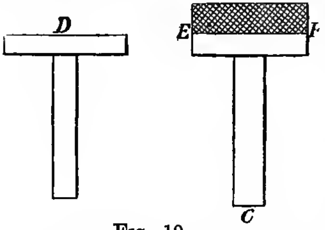


Fig. 19.

The mode of using is as follows :—An assistant is sent with C E F to one end of the girder, he rests end C on the flange, turning the chalked face towards the other end. A second assistant stands at the centre with one of the short staffs. The inspector, or foreman, stands at the other end, resting his short staff end on the flange; then placing his eye on a level with top edge, D, he sees white part of staff at opposite end. The assistant at centre holds his staff to the side of the flange in such a manner that it is interposed between the other two. He raises or lowers it until the inspector sees its top edge in line with that of his own and with line between chalk and wood, E F on C E F. When this is found, the centre staff is held steady till the distance between the flange and the lower end of staff is measured, and this difference shows with considerable accuracy the amount of camber. To make the process more clear see diagram Fig. 20, where the curved line represents the cambered flange: A B is the cross staff held at the centre, E F, the long staff with chalking, and C D the staff from which the level is taken. The principle involved is exceedingly simple. When the tops of A B

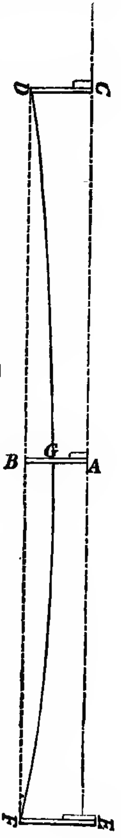


Fig. 20.

and C D are in line with E F on edge of chalk, it is obvious that the lower ends of all three staffs are in line, and therefore the space B G (Fig. 20), or distance between end of middle staff and flange, shows rise of flange. This will not, however, show whether the camber is uniform or otherwise. Of course if great accuracy be required, as would be with great spans, then a proper telescope level can be used, taking as many sights for ordinates as may be desired. This is very seldom necessary. We now come to the removal of the work from the yard to the site.

CHAPTER IV.

SINKING FOR THE FOUNDATIONS—PILING—MASONRY—BEARING PLATES—STAGING—WORK LEAVING THE YARD—DELIVERY AT THE SITE—LAYING DOWN—THE TOP BOOM—CAMBER.

THE contractor whose tender is accepted begins his work by draining out the water from where he is going to excavate. This is done in the river itself by placing iron chambers called caissons round the spot to be excavated, and pumping out the water from the interior. In special cases the work is done by divers, but such work is beyond the scope of this little volume. Keeping therefore to that under notice, where there are only the bank abutments, the contractor sends an experienced foreman or gaffer with a gáng of men and a large float, which they anchor securely at the bank. On it a pile engine is mounted, and the place is carefully enclosed by a row of piles driven deeply into the river bed, and as close as possible together, technically known as sheet piling. If the stream be shallow and not subject to high floods, a single row of piles may suffice, but more usually a double row is driven, and a space purposely left between them is filled up with clay puddle to make all water-tight. This being done, and a centrifugal or other pump driven by a portable engine provided to keep the enclosure free from water, the ground is dug out to the depth stipulated for in the specification, which for convenience of illustration we may suppose to be rock. When it is reached the fact is reported to the engineer, who visits the place in person if possible, or else he sends a trustworthy deputy who personally satisfies himself that the rock is really laid bare. Its surface may be fit to build on at once or it may have to be made so by blasting. Individual cases

require individual treatment. The abutments are then built, and as the files of the leading engineering and architectural journals contain numerous excellent drawings and specifications for work of this nature, it is sufficient here to refer our readers to them for instructive examples; this little volume pretends only to deal with manner, not with matter.

The masonry of both abutments is carried up to the height required by the engineer, who may specify that the top surface shall be so many feet above the Ordnance datum, or datum on which the Ordnance Survey of the country is being carried out.

The corner, top, or cap stones of the abutments ought to be as large as possible and free from cracks or shakes, because the main girder ends will rest on them, and they have therefore to sustain the entire weight of the bridge. The iron of the girders does not rest directly on the stone. Cast-iron plates, such as shown at Fig. 21, are laid upon the cap stones, into which they are tongued or recessed. Fig. 21 shows three views of the bearing plates upon which the fixed ends of the main girders are rested. The length of bearing for bridges of the class under notice is from 4 feet to 4 feet 6 inches. The breadth of the main girder flanges may be taken at from 3 feet 6 inches to 3 feet 9 inches. The distance between the flanges C D of bearing plate is a couple of inches more than this. Indeed, such flanges are not necessary at all. The cap stones of the abutments are channeled and cross-channeled till four projections are formed, which fit the

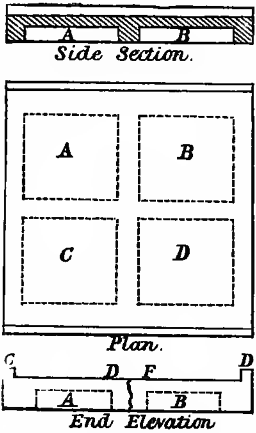


FIG. 21.—Three views of bearing plates for fixed ends of girders

recesses shown in Fig. 21 at A B C D. The bearing surface, F, is brought level with the general surface of the stone, and cement in a liquid state is run in after the plate is laid, completely filling up every crevice between the metal and the stone. Very great care is necessary in setting these plates. They must be perfectly evenly bedded and supported by stone or cement at all points, otherwise the weight, one-fourth of the entire bridge and its load, placed upon each will crack it. The proper way to bed any of these plates is, after it is approximately fitted, to coat it well with red paint on its under faces. It is then to be lowered into its place, and after resting to be hoisted by the crane; all the places where it touched the stone will be of course marked with the paint. These must be cut with a chisel and mallet, and the plate again lowered and raised and more chiseling done, until the stone is marked with paint all over.

Where the cross girders are rested on one edge of the lower flange of the main girder, their own weight as well as that of the flooring and roadway has some little tendency to incline or tilt it out of plumb, though as the cross girder ends are firmly riveted to it many engineers are of opinion that no such effect can ensue. However, it has been the author's practice to cause the bed plates to be set with a very slight inclination outwards, so as to correct any possible error from this cause.

About bridges of a single span it is rather matter of opinion whether it is necessary to fasten the main girders at one end. Some engineers say it is as well to do so; others see no need. The author has seen drawings of bridges where bolts and nuts were shown as fastenings, which is a very unpractical idea, for the simple reason that of course the bolts must be put in their places in the bed plates before the latter are set on the stones; and if the main girders are built respectively in their final positions, it is a thousand to one against the bolt holes in the flange plates exactly coinciding with the bolts. The author's

practice has been to get the girders built and into their places first, and having omitted two or four rivets in bearing end of the main flange, he caused holes to be drilled with a ratchet and brace concentric with them in the bearing plates below. Steel or iron pins slightly taper at their very ends, and for the rest of their length same diameter as the holes, say $\frac{7}{8}$-inch, are provided, and these being driven in firmly, stake the girder ends. A sheet of felt, either plain or tarred, is placed between flange and bearing plate.

Of course the other ends of the main girders must be free to move on account of expansion and contraction. The bearing plates for the moving or free ends of the girders are similar to what is shown at Fig. 21, the only difference being that the surface on which the girder end rests is ribbed and channelled instead of being smooth. This is done with the idea of reducing friction, and a sheet of felt is used here also between girder and plate, and sometimes a sheet of lead is put down. Very frequently girder ends rest on friction rollers, though this practice is one of debate amongst engineers, some advocating them, while others assert that the limit of their motion is so extremely small that they rust into fixtures very soon. As regards building or putting the bridge together, various systems are pursued according to the circumstances of each individual case, and also according to the opinions of this or that contractor, as to which is the cheapest method. Sometimes a separate staging is made on which to build each girder at once in its place. The more usual way, however, is to construct one stage in the middle of what will be the roadway line of the bridge, and then to build either one girder at a time or both close together at once, and then to shift them, the one "up stream," the other down stream, to their final resting-places, or else one may be built at a time and then the other. This, however, is not a prudent method, because of course much more time is needed, and as all rivers are subject to floods which may probably cause serious

damage, it is expedient to get the work completed with all convenient speed.

The staging consists of balks of timber driven firmly as piles into the bed of the river, care being taken to leave clear way for barges or any other traffic up and down the river. These piles are tied and strutted with other timbers; transomes are secured, and a boarding of battens laid down. Next a series of blocks are laid down carefully in line and set at levels to suit the curve or camber of the girder. The ironwork is usually all delivered at one side of the river. A strong hoarding of plank fence is erected to keep out the public, a wooden house is made for an office, a smith's shop is constructed, and a gantry and traveller is provided.

We may now return to the girder yard. The engineer or his representative having passed the work there, the job of pulling down and sending away begins. At this period the engineer or clerk of works is introduced to a man he possibly never before laid eyes on or even heard of. This is one of the contractor's out-of-door foremen. A person who is to have charge of the erection of the bridge is generally a sub-contractor, who, although in the regular and sole employment of one firm, still contracts separately for each erecting job he undertakes for it. He undertakes to erect the bridge for a fixed sum, and the system entails a good deal of trouble on the inspector. Obviously it is the interest of the erector to build the bridge as inexpensively as possible. He can hire his own men, and as many or as few as suits him, and those he employs may or may not be skilled workmen, particularly to do what is called platers' work. In a case of this sort the various parts are moved from the "bank" to the place of fitting by ordinary labourers, men drawing lower wages than platers; these latter work the various parts into their respective places and service-bolt them there. These men to some extent correspond with fitters in machine shops. If unskilled men are employed the parts will be thrown together "anyhow," and even the

best prepared work may be quite spoilt if improperly fitted at the site. The inspector consequently must insist upon every part being very carefully put in its place, and everything drawn together thoroughly in the bottom flange before the building of the top commences. He ought to instruct the erecting foreman in writing to examine the girder as it stands built in the yard to see all right before it is sent away. This will prevent subsequent complaints from him at the site, for if the work is bad at the site, of course he will lay the blame on "the yard;" but if the inspector knows his business, has satisfied himself in the yard that all is right there, and, as has just been said, cautions the foreman while the work is there to examine it, and complain if he sees occasion, of course the latter cannot very well say anything afterwards.

We may now suppose that some of the iron is delivered at the site. A gantry and traveller will have been erected at that side of the river at which the iron will be delivered, and it is used to unload the trollies conveying it from the canal dock or railway goods yard.

The foreman will have got all the bearing blocks in readiness for receiving one or both lower flanges; he will set a number of labourers to seek out all plates whose marks indicate that they belong, say, to the centre of the girder, and these are either pushed forward on rollers with pinch bars, or are hauled along on the rollers by a crab and chain, or they are put on a very low sort of truck and pulled along. A number of them are at last got together, the foreman himself, or the foreman plater, directing all and seeing the plates laid correctly in accordance with the marks. These are drawn and pushed till exactly in their places, when bolts of a coarse kind, known as "service bolts," are put in a few of the rivet holes to keep the work together. Other plates are added on and bolted, and if the setting out and drilling, &c., has been well done in the yard, all must of course be a good fit here; but then the foreman must know his business, and employ, as before

observed, competent platers, a superior and more skilled class of men than mere labourers, to work under him, otherwise the work will be badly fitted and put together, and will be made to seem as if badly made "ab initio." Very great care must be taken to keep the plates well drawn together as fast as they are laid down. Every plate should butt in close contact joint with its companions. Nothing is more indicative of bad work than gaping joints, and they are caused by the rivet holes being drilled too close to the edge of the plate. The usual distance at which rivets are pitched in work of this sort is 4 inches, therefore rivet holes ought to have their centres just 2 inches from the end edge of the plate, for if less than this, when laid over or under another plate, if its end butt to the companion plate all its rivet holes will be out of concentricity with those in the other plates, or if the holes are brought right the joint will not butt. And here it may be remarked that the system of marking and drilling the plates individually from one carefully drilled template is more likely to secure close joints than is the system of cramping all the plates in position and sending a travelling drill over them; for this reason, that no matter how careful workmen may be, it is nearly impossible for them to lay together a number of plates, weighing from half to three-quarters of a ton each, so exactly that all will butt closely together, so closely that a strip of crinoline steel will not pass between them, and not only are they to be laid thus, but they must be cramped there, and never shift in the least till as many as 200 rivet holes have been drilled through them. Many manufacturers, however, object to this separate system of marking and drilling as being more costly, owing to the greater amount of handling which the stuff gets.

The drawing of plates into position in the process of putting a bridge together brings up a question of practice about which engineers and contractors hold widely dissimilar views—namely, the use of the tool called "the drift." Under certain circumstances and used with due caution it

is almost indispensable in putting heavy ironwork together. Drifts have been described at pages 8 and 9.

The plates are usually taken hold of by hooks of the shape shown by Fig. 22. The hooks being inserted in the holes near the plate-edge the workmen are able, partly by them and partly by small crow or pinch bars, to drag and shift each plate approximately into its place. It can be readily imagined, however, that the plates need subsequent "fitting," that is, they require to be adjusted exactly in their final positions; if they are not, then the rivet holes will not truly coincide, and the plate ends will not butt close. Now the bottom or top flanges of such large girders as those under notice may have twelve, fourteen, or even many more plates piled one upon another, and suppose the first six or eight to have been got into their exact places, the operation of putting down the next plates will more or less shift some of them, very little perhaps, it may be only an eighth of an inch, but still they are moved and must be replaced. The plates above, however, press upon them, and partly from the friction thus caused, and partly from their own weight, a force is required to effect the replacal, and there is but one way of applying force, namely, by driving in a drift If the plates are vertical, or if they are some feet from the ground and horizontal, then the proper form of drift to use is the parallel, and it should be only a shade less in diameter than the size of the rivet holes. This being driven in by a four-pound hammer, all the plates being loose, it will draw them up to their right places. Two drifts ought to be used, and at holes as remote from each other as can be. This will bring the plates right in both directions. Where the plates are horizontal and too close to the staging to admit of using a hammer to drive the drift back again, either a short parallel or else a barrel drift must be used,

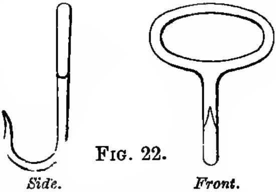


Fig. 22.

such, in fact, as can be driven right through and got out beneath. Once a tier of plates is got into true position at least two service bolts should be put in to prevent any shifting. They should be of a diameter to fill or fit the holes. As fast as one set of men get a portion of the bottom flange laid, others follow them up with the vertical plates uniting the lattice bars to it. The sketch (Fig. 11) shows them at C D. The plates are united to the main flange by the angle irons as shown, the lattice bars pass between them, packing pieces being used to fill up blanks as distance pieces, and rivets are put through all. These plates then and their angle irons are then got into position, and secured with service bolts. Next the lattice bars come. Now a usual proportion of depth of girder to length of span, is from $\frac{1}{10}$ to $\frac{1}{12}$; so that if a girder be 150 feet span it will be $12\frac{1}{2}$ feet deep. The lattices are usually set, either at an angle of 45° or at one of 60° with the horizon. If at 45°, then their length will be about 17 feet; they must be raised and swung to their places by means of a derrick pole and a purchase block. In like manner the plates for the box-ends or pillars, as they are technically called, of the girders are got into position. In large girders such as this there are two plates in each side of the box, and they are united, as are all web-plates of girders, by means of tee-irons; in cases like this double tees are used, as in sketch Fig. 23, see A B, while at C is part of the back end plate, up to which the masonry of the abutment is built. All these are successively arranged and bolted up. The end plate, however, is sometimes left till the last. The author himself has superintended the erection of a bridge whose lattice bars were too close to each other to allow any one but a small boy to pass through, and the girder being a double or box lattice, it was necessary to leave the end plates off till the last moment. The

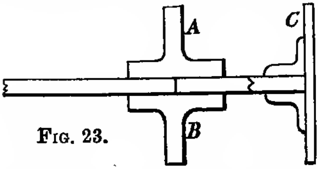


FIG. 23.

top boom or flange is the same as the bottom flange; so when all the lattice bars are got into place, the plates corresponding to C D, Fig. 11, are raised up, fitted, and secured, then the angle irons, and finally the main plates themselves. The girder will now begin to assume form and shape —to look, in fact, something like what it is going to be. It is, however, increasing rapidly in weight, attention therefore must be given to the wedges on the blocks sustaining the whole structure. Every day now the danger becomes greater of the girder sinking and losing its proper camber; every day also adds to the difficulties to be encountered, should it become necessary to raise the girder at any point or throughout in order to restore the camber, and now will be felt the truth of the advice given farther back, viz., that it is no harm if the blocks are arranged to allow of a little settlement. A girder such as this might weigh about 120 tons. This is a heavy load for a series of mere temporary timber blocks to sustain for, it may be, some weeks.

All that has been said about trueing the camber in the yard applies here with even greater force. This is final; the future duration, the permanent soundness of the bridge will depend on the way the work is now put together. Even one plate not drawn truly home to its place will spoil the coincidence of a large number of rivet holes in three plates, its own and those at each side. The rest of the work may, despite of orders to the contrary, get riveted and the displaced plate become so locked that no *legitimate* amount of drifting, no drifting that any clerk of works or inspector who knew his business would allow for one moment, will draw it right. The close and unremitting attention of the foreman himself must, therefore, be given at this stage of the work. It is sometimes argued that *close butts* are not essential in a bottom flange because it is in tension, but it is often too certain that if bad joints are tolerated in the bottom of the girder attempts will be made to slip them past at the top, where, as the work is in

compression, it is highly important they should absolutely butt, so as to maintain the proper crushing area of metal Minute care must also be taken to see that the lattice bars are set quite true, and that the holes in them are truly concentric with their companion holes in the plates and angle-irons.

CHAPTER V.

BOLTING UP THE WORK—RIVETING—HEATING LONG RIVETS—RIVET FURNACES—COMPRESSION STRESSES—MOVING MAIN GIRDERS—SETTING THEM TRUE—SETTING CROSS-GIRDERS.

As soon as all the plates and angle-irons of the top flange are got in place and secured as it were temporarily, the foreman should make a good and searching examination of the work, effecting all requisite adjustments and alterations necessary to bring every part "true" with the rest. It will save him from being called to task by the clerk of the works or the inspecting engineer when he comes round.

Every care should now at the last moment be taken to insure the truth of the camber. When all is right, the whole work must be carefully bolted up with good service bolts, which should be made of at least a moderately good quality of iron, though some contractors use such poor stuff that work cannot be properly forced tightly together. Nothing makes or causes bad loose riveting more than bad loose bolting up. Plates partly drawn by indifferent service bolts are drawn closer by the first few rivets; the succeeding rivets bring up the parts close, and all the first rivets are so loosened as to become mere clinkers, capable of being shaken by the finger and thumb.

It constantly happens that certain rivets are not to be put in until the bridge is advanced it may be almost to completion. The holes for these ought to be either chalked or, better still, painted round. Cross girders may have to be riveted; cast-iron work, ornamental or other parts may have to be fitted and fastened, and it is always objectionable to cut out rivets, and never should be done unless for some very important reason indeed; doing so racks and spoils work very much.

The girder is now ready for the riveters, who, of all men

in the iron trade, work perhaps most by piece work, being paid either by the score, by the hundred, or, as is sometimes done in chain riveting, by the yard; but all comes to much the same thing in the end.

Five persons go to make a "gang" of riveters, three men and two boys. Of the men one puts in the rivet and then "holds it up," while the other two men hammer it down and snap it. The holder-up is provided with a sledge of from 7 lbs. to 10 lbs. weight, having a cup recess in one of its faces, a shape to fit the head of the rivet, which is usually formed to resemble a cheese; hence the name "cheese-headed." The sketch, Fig. 24, shows it. A careless workman will sometimes hold up with the flat face of the sledge, and the result is that the rivet head becomes flattened down and defaced; this of course should not be allowed.

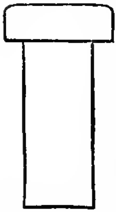


FIG. 24.

The whole system of fastening plates and bars of iron together needs some notice here, though we must direct the student desirous of more perfect information about it to Fairbairn's, Reed's, and other standard books of reference. The mode of testing rivets has already been described. A rivet should be about one and a half diameters longer than the hole. It should be heated all over to a bright, nearly white, heat. It is the special business of one boy in each gang to heat the rivets, which he does on a small open hearth, having a bellows beneath. He works his bellows with one hand and turns the rivet in the fire with the other. He is considered a skilled artisan, because he must know how to heat his rivets sufficiently without burning them. A burnt rivet is worthless, and when one is burning the matter can be known by the peculiar scintillating sparks that fly up. When a rivet is thus burnt all the "nature" of the iron is destroyed, and it ought not to be used. Of course many different lengths of rivet are needed, varying from about 1½ inch up to 18 inches or more. A little diversity of opinion exists among engineers as to

whether a long rivet should be heated all over, but the greatest number are in favour of the practice. Indeed, the only objections advanced against it is that the great amount of contraction ensuing on the cooling of a long rivet entails so great a tensile strain that either head is caused to fly off; with good rivets this never occurs. There are good reasons for heating rivets all over. One object in heating is that as cooling takes place so does contraction, and the plates are thereby drawn tightly together; the more contraction is obtained the tighter the work. Another object is, that as the rivet end is beaten down, part of its shank is upset and thickened, thereby filling the hole tightly. This last effect only results in the case of rivets closed by hammering for a distance of about an inch below the hammered end, as may be seen if a rivet be cut out and examined. A different result is obtained if the rivet is closed down by a machine. A hammer only dints the end; its effects are too sudden to allow time for them to extend far, somewhat on the principle by which a candle may be shot through a plank without damage to the candle other than a little just at its end; let the candle, however, be pressed up to the plank by hand, and if supported to prevent its breaking it will crush up. Indeed, so greatly is a rivet shank swelled out by machine pressure that the edge of the plate round the hole is often bulged, and sometimes, with inferior plates, split.* As yet, machine closing cannot always be resorted to for work involving the use of very long rivets, which is unfortunate, as this is just the class most needing it. Where machine riveting is used for a pile of more than two or three plates the work must be most carefully bolted together.

Great difficulty is always experienced in getting rivet boys to heat any but very short rivets all over. The influence of piecework operates here. It takes more time to

* The following pressures are used in boiler machine riveting:— $\frac{3}{4}$-in. rivets, $\frac{3}{8}$-in. iron plates, 38 tons; $\frac{3}{4}$-in. rivets, $\frac{1}{2}$-in. iron plate, 40 tons; $\frac{3}{4}$-in. rivets in steel plates, 45 tons.

heat six or eight inches of iron than one or two inches, in the small fire used for the purpose: long rivets, white heat all over, give the men also a little more trouble, because if they are a tight fit in the holes they need gentler measures to get them in, as they will not bear much hammering. As long as the boys are looked after pretty closely all will go right, but if left to themselves they will send off rivets only heated properly just at their ends. The only effectual remedy would be to heat the rivets in a little stove or miniature furnace. The author has seen such—a perforated plate or shelf being set above the fire in a casing, the rivets being dropped one in each hole and resting on the shoulder of its head, the whole affair resembling Fig. 25, which shows sectional side view. A is the casing, B grate, C perforated plate with rivets D D, E is door for placing or removing rivets, F is fire-door, G ashpit, H blowing nozzle, J J legs of any convenient height or shape, K uptake, which may be placed of course at side of case if desired. It will be seen that the rivets are in a species of combustion chamber, do not come in direct contact with the fuel, and are surrounded by a temperature practically uniform at all points. As to details of construction they are simple and susceptible of sundry variations. Thus the top cowl may or may not be detachable, or the upper portion of case may be detachable from grate and ashpit, and so on. This furnace may be made portable. Another form, larger and not portable, regularly

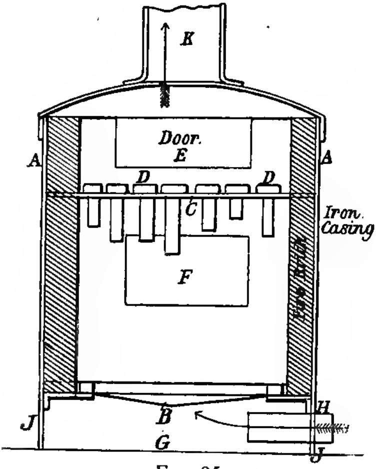


FIG. 25.

built of brickwork, is shown at Fig. 26. It simply consists of a furnace A, and hearth on which the rivets are laid, and the hearth may be, say, 12 or 15 inches wide. In this furnace also the rivets are heated equally all over, and are not in contact with the fuel.

When the work is about to be riveted up judgment must be exercised as to the parts riveted first, and those which it may be expedient to leave to the last moment. As riveters object to any change from place to place, wishing to rivet right ahead, it is wise to start them judgmatically, because, for one thing, certain holes must, as has been before observed, be left to the last moment, and also be-

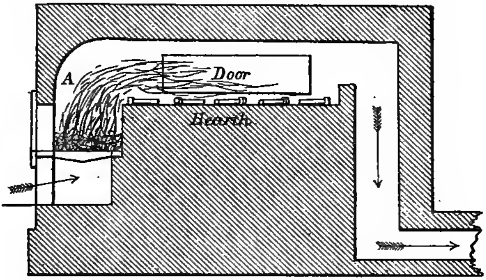


FIG. 26.

cause plates are stretched, very slightly, it is true, but still there is reason to suppose extension does take place, and it may be in certain places turned to account to force joints close home. For example, the flanges of the main girders ought to be riveted from either end towards the centre, because the doing so extends the plates toward each other, whereas if riveting were done from centre to ends, whatever extension attended would work towards unriveted plates and be lost. If circumstances, however, preclude riveting from ends to centre, then, at all events, some rivets can be put in at each set of plate ends, which would secure the plates, preventing any yielding on their part. Where the

workmanship as well as the first setting out has been well done, the method of riveting described here will actually, to some extent, increase the camber of the girder, relieving the blocks on which the bottom member rested.

The arrangement of parts in the top of the girder are the same as those adopted in the bottom, but the nature of the stress it has to sustain is exactly, of course, the reverse of that borne by the bottom, the latter being subject to a tension the former to a compression load. As a point of good workmanship, the plate ends of the lower member ought to butt in contact equally as well as those in the top, but there is no absolute constructive reason otherwise why they should; the joints of the top should butt in close contact all over. The ability of wrought iron to resist crushing is less than its power to sustain tension, and where joints in a top member do not butt in close contact before the supports are removed, the crushing area of iron is diminished in the proportion borne by the area of any given open joint to the area of plate cross solid section in the same plane with it; as, for example, see Fig. 27, where a pile of eight $\frac{5}{8}$-inch plates are shown, seven of the plates solid, the eighth having a joint as shown. If this joint does not butt in contact the crushing area of plate is reduced to the extent of $12\frac{1}{2}$ per cent.; a very serious reduction. Serious, in the first place, because, assuming as we ought that economy of material, as well as the exclusion of redundant strain due to the presence of useless material, has been carefully studied in the design of the girder, so large a reduction of area as $12\frac{1}{2}$ per cent. cannot be spared, and if it be assumed that eight plates are at or near the centre of the span, as a matter of course a less number, say four plates only, are at the ends, here a gaping joint reduces area by 25 per cent. It may now be supposed that both main girders are riveted up complete,

Fig. 27.

or as complete as they can be before the cross girders are put in. If they have been built near to each other the next step is to shift them into their places. The following is a description of the moving of a pair of main girders, effected in the construction of a bridge with which the author was professionally connected.

The span of the bridge is 125 feet, the breadth of the road and two footpaths collectively 44 feet; each girder 133 feet long over all, 3 feet 6 inches wide and 11 feet 6 inches deep; open bottom double lattice type, weight of each 110 tons. A cast-iron bracket, such as is shown in Fig. 28, was bolted to each end plate of the girder

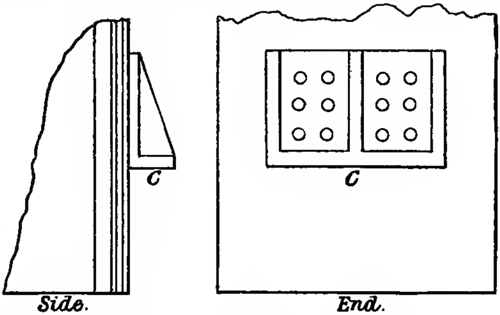


Fig. 28.

The height of face c from ground was about 3 feet. A hydraulic press, having a ram 4 inches diameter and 5 inches stroke, was provided. It was made of cast steel and was easily carried by two men. It was rested upon a balk of timber laid close to girder end, its ram head bearing against the bracket. A number of iron plates, of thicknesses varying from $\frac{1}{8}$ to $\frac{1}{2}$ inch thick, were provided, and all being ready the work was begun. Four men under the supervision of the foreman did all the work —viz., two at the pump, which had a ram $\frac{1}{2}$ inch diameter and about 3 inches stroke, a single-lever pump, drawing from a common zinc pail full of water. The second two

men were, one at each side of girder. According as girder was lifted these men put the iron plates under it; first a succession of thin plates, then these were quickly withdrawn and one thick plate substituted; on this again the thin plates were successively placed, to be again succeeded by a thick plate. By this means, in the event of the press breaking, the girder could not fall more than the eighth of an inch. When it was raised about 4 inches, a well-greased railroad rail was laid along the abutment, having one end run under the girder, which was then allowed to settle down upon it. The other end of the girder was dealt with in the same way, and thus both extremities rested upon greasy rails; and the next step was to shift it along these to its final position. The press was now set in a position inclined in the direction in which the girder was to be moved, and the angle of inclination was about 55° with the horizon. The pumping was then resumed, and the end of the girder moved along the rail, the top of the press moving over with it, of course. When the girder had moved 4 or 5 inches the press was moved to its other end, and the same process gone through, and so on till it was brought to where it was to rest. The press was now again set vertically and the girder lifted sufficiently to ease the rail, which, after packing, or, as they might appropriately be designated, safety plates were put under, was withdrawn. The girder was then gently lowered, plate after plate being withdrawn just before the girder began to "nip" it, till bed-plate was reached.

The same process exactly was pursued for moving the second. The time occupied in moving the first girder was four and a half days. The second girder was moved more expeditiously—namely, in about three days, the men being more self-confident about the job. All that is required in putting down a first girder is to set it fairly in the centres of its bearing plates; the placing of the second demands minute exactness, because of the fitting of the cross girders, which may rest on angle-iron of bottom boom and butt against a packing piece placed between its end plate

and the plate of the main girder to which the lattice bars are riveted (see Fig. 29, plate P). Fig. 29 shows a cross girder in place on a main girder; and in laying down second main girder in position it must be so accurately set

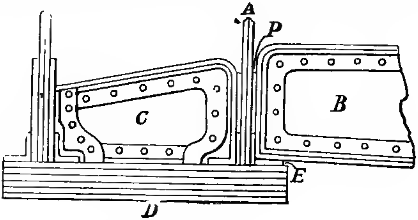


FIG. 29.

as that the distance between the angle-iron E and the corresponding angle on the other main girder shall be precisely equal to length of cross girder over all, for reasons made obvious by the illustration; C is a strengthening gusset.

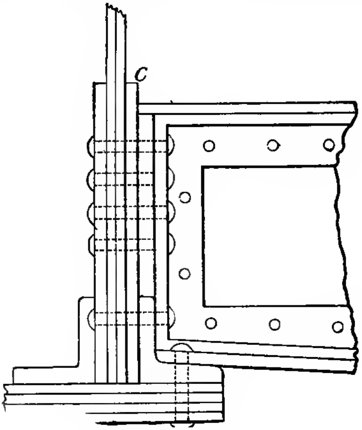


FIG. 30.

It is convenient to remark here that another method of fitting cross girders is such as that shown in Fig. 30. In Fig. 29 the top plate of the cross girder is carried all the way at the end down to bottom, a packing piece, P,

being inserted, as shown; while by another arrangement, Fig. 30, the top plate is stopped off at top of main girder angle-iron, and rests upon it, butting against lattice plate of same. The design of bending top plate of cross girder round at a radius as large as three or more inches is troublesome and not quite easy to fit; therefore it is expensive, and the author is of opinion that the design of this detail shown in Fig. 30 makes every way a sounder, simpler, and better job. Here the top plate is merely taken straight out and cut, so as to go over the end plate, which is separately riveted on. By going over instead of butting against it all the support attained by bending, as in Fig. 29, is pre-

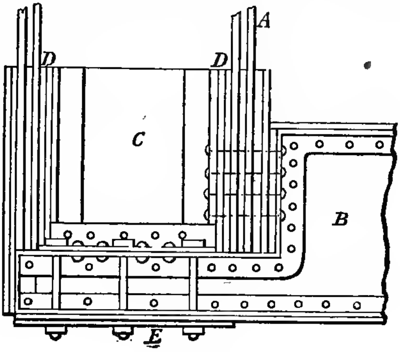


Fig. 31.

served, while the method of construction is much simplified, Fig. 31 illustrates another method of securing cross to main girders; it is adopted with what are known as open-bottomed girders, the main flange plates D D being arranged, as shown, in two vertical sets instead of in one horizontal pile as in Figs. 29 and 30. They are transversely braced by cross gussets O, secured to them by angle-irons. The cross girder B has its ends stepped as shown, and its upper part butts against, and is riveted to, main plates, while its lower part extends under main plates and gussets, and is bolted and riveted to the latter. This makes a splendid job.

CHAPTER VI.

PUTTING IN CROSS GIRDERS — SQUARING THEM — LAYING FLOOR— ASPHALTING—CAST-IRON COPING.

THE main girders having been got into their final position, the next step is to get in the cross girders. A variety of methods can be adopted for effecting this, of which the following constitute examples.

First method. The cross girders being all alike, they may be taken indiscriminately as they come to hand where all are of equal length, which, if due care has been taken in the design they will be, unless in the case of skew bridges, or those spanning a river or road otherwise than at a right angle, and which are called straight bridges. In skew bridges one or more of the cross girders at either end are necessarily shorter than the others, and one end is secured to the main girder while the other rests obliquely on the abutment. The number of these, as well as their respective lengths, vary with the extent of skew of the bridge, but, except in length, there is no difference between them and the others, and this is a convenient place to draw attention to the expediency and wisdom of designing all the members of a bridge, or any similar structure, so that they shall be all identical and interchangeable ; for in such a bridge as that under notice the cross girders would be, say, for present convenience, 50 feet long, 4 feet deep at centre, 3 feet deep at ends, and are underhung; that is to say, the ends of their top flanges are bolted and riveted to the bottom flanges of the main girders, as illustrated at Fig. 33. This arrangement very considerably facilitates the process of getting the floor plates into position in

straight bridges, because their tops when in place are practically on a level with tops of the abutments.

The cross girders have been unloaded from the carriers' trollies by the travelling crane, and are piled in readiness. As they are delivered anyhow, and would number, for a bridge like this, from 26 to 30, and weigh from 7 to 9 tons, the great importance of being able to use them "as they come" will be at once seen, because the least expensive method of placing them is to do so consecutively, beginning with underhung girders at the side or abutment where the girders are lying; and if they differed one from another the expense of labour and time involved in shifting a number of them to find No. 1 or No. 7, &c., can be readily comprehended.

In the case of underhung cross girders the abutments are not uniformly level throughout, if the bridge is a skew one. They could not be so unless recesses as deep, as wide, and as numerous as the short girders, whose ends must rest upon them, were made. Practical reasons render this less desirable than to lay bearing stones built in the abutments standing sufficiently above the general level of the abutments to make a difference between the under side of the main girder and top of the rest of the abutment equal to the depth of the ends of the cross girder, and thus the latter, when secured under the main girder, rests level upon the abutment also. Fig. 32 shows this with sufficient clearness to make plain the foregoing description.

It will be seen that there is a difference of level between the general ground and surface of abutment, and the underside of the main girders, equal to the depth of the cross girders. It is perhaps as well to point out also that the ground for some distance at either side of the river or road is still in a primitive state, the roadway leading on to either end of the bridge not being constructed, nor can it be till the ironwork and the main parts of the stone work are first complete.

The work of putting in the cross-girders begins, as has

been said, at the side where they are lying, but as to whether the short or long ones are first placed depends upon the opinion of the particular foreman in charge for the contractors. In this case it will be supposed he decides to put the short ones in first—to begin, in fact, from the very beginning. If he is a man who knows his business he will have taken care to keep his short girders separate from the rest, so that they are at once available without useless shifting of the others. The gantry on which the travelling crane, or to be more exact, on which

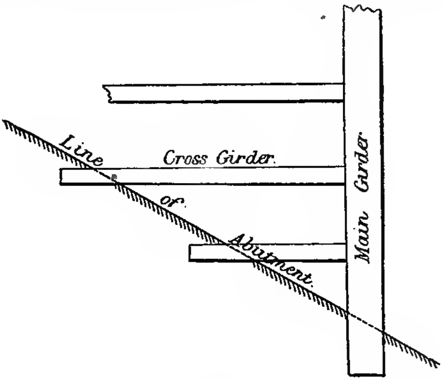


Fig. 32.

the lifting tackle travels, is constructed so that its terminus may be as close to the abutment as is possible. This is usually within 8 or 10 feet of the extreme edge of the abutment, or of its nearest point in the case of skew work.

Part of the working plant required for jobs of this nature are some rollers made of cast-iron. They are from 4 to 6 or 8 feet long, and from 3 to 5 inches diameter, cast-iron tubes, some $\frac{1}{2}$ to $\frac{3}{4}$ inch thick in substance, with a number of $\frac{1}{2}$-inch holes cast here and there in them radially.

A number of these are laid upon the ground within the

reach of the gantry. The lifting tackle on this—technically known as the traveller, and in future referred to as such—is brought over the first girder required, lifts and conveys it over the rollers, upon which it deposits it end on towards the river. It is next rolled forwards as near the edge of abutment as is practicable, either by a gang of men with pinch bars, and shoving, or else by the aid of a crab or windlass, and a snatch-block hooked to a lattice bar of a main girder. A block and tackle are now secured to the lattice work of main girder, immediately over the point where the cross girder is to be secured; another tackle is secured very carefully to or near the end of the cross girder, which is to come under and be secured to main girder. The rope or chain uniting the two tackles is now hauled, either by a gang of men or by a crab, preferably the latter, and the girder, to quote a sailor phrase, "slewed," or canted round, the rollers being shifted as it moves till it is got in its true line at right angles with the main girder. It is then drawn and urged carefully forwards till its end is nearly in its right position. It is now shifted to and fro, till at last one of its rivet-holes is brought into something like a line with its own corresponding hole in main girder; a taper drift is then gently driven down from the main girder through both holes, and acts as a steady pin. The farther end of the cross girder is then shifted with crowbars till the other holes in both girders correspond.

The tackle is now hauled upon till the cross girder end is lifted up as close to flange of main one as the strength of the tackle will admit of. Service bolts, already described, are now put in some of the holes and screwed up tight. These draw, or should draw, cross girder up quite tight to main one. The tackle is now taken off, and in technical parlance, the first cross girder is "in." Its end resting on the abutment neither needs nor gets any fixing just then. The next step is to construct a sort of gangway, or ramp, between the top of this first cross girder and the ground

level within reach of the traveller. This is made with rough stones, and planks or battens laid upon them. The tackles on the main girders are now detached and hooked over the points where, assuming the next to be a full-length girder, it will come. The required girder is slung by the traveller, and carried forward as far as possible, and lowered end on to the river, and deposited as its predecessor upon the rollers. A check-rope and tackle are laid off behind, or away from the river, and secured to the girder, as a safety gear to control its forward motion and guard against overrunning.

The first girder was the easiest to get in, as it had not to be lifted once the traveller put it on the rollers. It was also shorter length, and every way more manageable than will any of its successors be. It only needed a tackle at one end; all the others, save and except the short one at the other abutment, must have tackles at both ends. The short one could be slewed round on the hard ground of the abutment, the others cannot. The second cross girder, its tackles and check gear being fitted, is hauled and urged by crowbars up the ramp, and the critical part of the job begins.

Methods and conditions of work of this nature vary so much that in a treatise like this certain particular ones only can be assumed as illustrations, such assumption by no means implying that the methods here described cannot be varied, and it will suffice to say that if the two main girders had been built as previously described on a central stage, that stage must of necessity be removed before the cross girders could possibly be put in, because they would come below it. It will be understood that there is ample space for a man to walk to or fro inside the lattice work of the main girders on their bottom flanges, if so constructed.

The cross girder is now hauled forwards by the chains and tackles at either end till it is as it were launched into mid air from the girder previously fixed, the check gear steadying it. By dexterous management of the slings and

tackles it is lowered till its top surface is below under side of main girders, being slewed at the same time obliquely, so as to clear them. Being lowered sufficiently, it is again slewed back nearly to a right angle with main, or parallel with first cross girder, and like it raised up till it is close to main one. As before, a taper drift is got into a pair of holes at one end, and then the other end is shifted about till a second drift can be in like manner got into it. After this both ends are service-bolted up and made temporarily secure.

Battens or strong planks are laid as a platform over the two girders thus laid, and a third is brought forward by the traveller. The tackles and checks secured, it is hauled up the ramp along the bit of platform, launched, got in place, and secured.

There is no need to say more than that as each is got in place and made fast the platform is extended, and the tackles moved back on the latticing of the main girders till they are all in place. It is at this time that any error in the placing of the two main girders becomes painfully apparent. If they are not exactly the same distance apart at all points as will suit the cross girders, the holes for the bolts and rivets in both will not correspond, and a good deal of delay will be caused, as well as expense also in shifting one or other of them. Longitudinal error also may be found, owing to one or other girder being so placed that when the holes in one end of a cross girder and their fellows in the main one match, and the two girders are truly square one with the other, the holes in the other main girder are not concentric with their fellows, owing to this or the other main girder being too far in, or not far enough so on one abutment. Here again the hydraulic jack and labour and time have to be called on to move it till the holes match. Of course if the ironwork has been properly made in the yard, when one long cross girder is got right all the others will come right as well. This teaches a capital practical lesson to young engineers of the abso-

lute necessity for having every step in such construction taken correctly; no sluring or passing over, no saying, "Oh, it will all come right at the site," being allowed for a moment. In work of this kind there is no going back, no retracing of steps, therefore every step must be a right step.

As soon as it is certain that a cross girder is properly in its place, the requisite holes may be drilled in those ends of the main girders which are to be fixed, and the stakes or pins driven, care being taken to secure both to the same abutment; if this is not done there will always be some danger of a strain, due to expansion and contraction, being put on the rivets securing the cross to the main girders, owing to a want of uniformity in the motion of the two latter.

Another method of putting in cross girders, especially those that are underhung, is by means of a derrick. A derrick consists of a single perpendicular pole or post, generally of wood, of sufficient strength, which is either known by experience or may be readily calculated from rules framed from elaborate experiments made at various times by able investigators of the subject. A block of three or more sheaves is fixed at the top of this, and, moreover, four strong ropes or chains, called guys, are carefully made fast at the same point. There is a snatch-block, or block with one sheave, secured also at the foot of the post; a block or tackle is united to these blocks by reeving a chain or rope through them all. A rope would run the smoothest, but there is considerable danger of its being cut or injured by the edges of the iron plates, &c., so chains are most commonly used. A crab or windlass is securely fixed on the abutment, in line as near as may be with the set of the snatch-block, as well as to suit the best method of securing the foot of the post against the side strain that will be put upon it by the pull of the chain. The derrick is "stepped," to use a shipping expression, on the edge of the abutment, and the four guy ropes are taken or led away to distant points, at about right angles,

drawn tolerably tight, and most carefully secured; these keep the post upright—these and these alone. If the post be truly upright and the guys tight and soundly secured, very little strain will come upon them, but the strain will rapidly increase upon any one or any pair of them in proportion as the post is inclined from it or them. The foot of the pole, if it were simply on hard ground, would neither need nor receive any better securing than the digging of a little cup or indentation in the ground for it to rest in. In the case under notice, where it has the first girder to put in, it is stepped close to the edge of the centre of the abutment, and some blocks of stone laid against its foot, especially at the side next the crab; much is not needed to keep it in place, because it has the whole dead weight of the girder forcing it down on the stone; while if the tackle be a six-purchase affair—that is, two three-sheaved blocks and six runs of rope—of course the strain on the rope as it goes off to the crab is but one-sixth of the weight of the girder, or at most here $1\frac{1}{2}$ tons.

A cross girder is now brought forward by the traveller and laid beside the derrick, a powerful sling is put round the centre of the girder, the centre being found with some care, so that the girder may hang reasonably in balance. A tackle is also secured to each end as a safety gear, and to swing or slew the girder, it is united to each main girder. Men now go to the crab and haul on the sling rope till the girder is clear of the ground. The two end tackles are hauled on so as to draw the girder towards them. As the derrick is about 15 or 18 feet high, and the cross girders but 5 to 6 feet apart, little difficulty is experienced in drawing the girder away from the pole as far as may be necessary, even if it be stepped upon the abutment; usually a balk of timber is laid, resting one end on some part of main girder, the other upon the abutment, close up to where the cross girder is to go. The girder is then worked up near to the post and the tackle brought to work; it of course draws it on and lifts it. It is then

slewed, lowered, slewed back again, and lifted close in its place, set and service bolted as before. The derrick is now moved forwards and again stepped on a timber laid from abutment and first girder, and projecting cantaliver fashion, or close to position of the next girder. The back end of this timber is carefully loaded with stones, to prevent its tilting by the pressure of the foot of the loaded derrick; a gangway is made, the next girder taken from the pile and brought forward by the traveller, worked on from it to the derrick, slung, and got into position as before. The same process is repeated all across till all the girders are placed.

A third and very simple method is also suitable where the breadth of the roadway or distance between the two main girders is not too great, say inside 30 feet, and the main girders are straight topped, not "bowstrings." This is to treat the main girders simply as a gantry. Fasten a couple of rails on them—they need not exceed two lengths at each side, as they can be taken up alternately and laid again farther on—a single strong timber well trussed laid across from girder to girder and fitted with a block and tackle, the chain being led off to the crab as before, and the cross timber being lashed to each main girder to prevent its shifting. Indeed, for simplicity' sake, the rails may be dispensed with and the ends of the cross beams rested simply on the girder.

This being set over the place where the first cross girder is to come, the latter is brought forward near to end of gangway and the sling secured; it is then swung off into its place as before, secured, and the gangway extended on to it; and the cross timber, also moved on another girder, is brought up, slung, and placed. The time occupied in putting in cross girders is much the same in either of these methods. The last is the most expeditious, but the heavy cross piece is a costly item, as it must be first-rate quality and a heavy balk well braced.

Cross girders, which are secured to the sides of the main

girders, resting on the flange angle irons, can be more easily put in by another method, if the main girders have been built upon a central staging. This staging is lowered by letting down the transomes, and rails are laid from one abutment to the other; a flat-topped truck on low wheels is put on it. The top table of the truck is slightly higher than the angle irons of the main girder. This truck is brought to the abutment, and as the main girders in this arrangement rest simply upon the ordinary level of the abutment, of course the top of the truck is also about level with it, so a cross girder is got on to it without the least difficulty. In the methods already described the laying begins at the near side; in the present case it begins at the farther side, for obvious reasons. When the girder is got well on the truck in an oblique horizontal position, so as to be clear of both main girders, it is either hauled along by a chain and crab or pushed by the men, till at its final place, when it is slewed round; small packing pieces are laid on each main girder angle iron which it is worked on to till clear of the truck, it is then adjusted into its final position and secured with service bolts, which in this case have only to prevent any possibility of its shifting laterally, but have no weight to sustain as in underhung girders, because the girder ends rest upon the main angle irons.

Of course the central railway and truck can be used for underhung girders as well, but all depends upon local circumstances and the views of the man in charge for the contractors. As to time expended, at least three ought to be put in in a working day of 9½ hours in good weather, and the number of men, including two on the traveller, about eight beside the foreman.

The next thing is to get the girders riveted, so planks are laid, forges got along, and work commenced. Owing to the cramped conditions it is very difficult to get nicely finished riveting done, and as it is not in public view it is not very necessary, but the soundest work is very essential even for the girders resting on the main girders, but it is

absolutely vital for underhung girders, as there is nothing but the bolts and rivets retaining them and the floor of the bridge in position. The sketch (Fig. 33) shows the way the rivets and bolts act.

There is the most perfect safety in fitting cross girders in this way, the united strength of all the rivets and bolts in any single girder being capable of sustaining at least one hundred times the greatest load that possibly could by any method be put upon them. Figs. 29, 30, and 31 show how the other girders are supported, and horizontal rivets secure their end plates and angles to the side or trough plates of the main girders. The sketch, Fig. 33, only shows the principle of securing. A great number of both bolts and rivets are

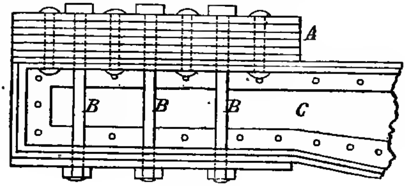


Fig. 33.

used to secure each end. But nevertheless the most careful supervision must be exercised over the men to ensure sound and reliable work.

While the riveters are at their work the process of laying the floor now proceeds; first the angle irons running along by the main girders are laid down and secured with service bolts. Next the tee-irons running in the same direction over the cross girders, marked T T T in Fig. 16, are put down. Certain holes were drilled in top plates of the girders and corresponding holes in the tee and angle irons by which they and the floor plates are to be riveted together, and to secure that they will do so the work must have been, as has so often been impressed on the reader, set out and carefully done in the yard. Besides this, however, the work must be properly laid together at the site.

and therefore it is extremely important that the cross-girders should be perfectly square with the main girders. This can be easily and accurately determined by triangulation. Mark a point on top of any cross girder close as possible to main girder. Take either a 10-foot measuring staff or a steel tape—a linen one will not answer—and mark off 12 feet, either on top of the cross girder, or on trough-plate (c, Fig. 30) of main girder, and make a mark with the punch. Now from first mark measure off 16 feet, either main or cross girder, taking care in the latter case to have the punch mark the same distance from the edge of the top plate as is the first mark. The annexed diagram (Fig. 34) shows the method in plan.

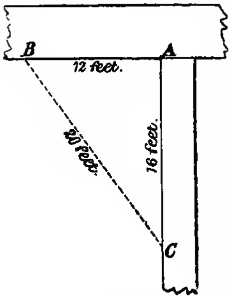


Fig. 34.

A B C are the punch marks. Now, if the cross girder is truly square with the main one, the diagonal dotted line, which is the hypotenuse of a right-angled triangle, must be exactly 20 feet. Any other proportionate numbers may be taken, such as 3, 4, and 5, or 6, 8, and 10, and so on, but they must be high numbers to give long lines, to secure accuracy. See also what has been said about underhung girders at page 58.

As fast as the angles and tees are put in position the labourers carry on the floor-plates, already described, and lay them down, and they are adjusted into their places with small pinch bars. If they have been properly squared at the mill, and bent and drilled in the yard, they will all come close up to the roots of the angle and tee-irons, which are sharp-angled thus , not round-angled thus , for this work, and will also butt close, level, and flush with each other; if they are not square and all curved equally, of course this cannot be the case, and the cover strips going over the joints of course cannot lie close to the lower level or least bent plate; where this is found to exist it entails

immense trouble and expense. These floor-plates average 12 feet long, 3 feet wide, $\frac{3}{8}$ inch thick, and weigh about 4 cwt. each; about 150 of them are required for the floor of such a bridge as the one under notice, or 30 tons, and the expense of getting these rebent to make them true can be easily judged.

When all the plates are down, or while they are being laid, other men are busy putting on and bolting the curved strips before referred to, which cover the plate joints and bind the plates together; they are secured by $\frac{5}{8}$-inch rivets, 5 to 6 inch pitch centres. Here also the work must be tightly bolted up before riveting, for reasons already explained. Some plates along at either or both main girders are left off till the last, to afford access to the underside of the floor for purposes of riveting. Short pieces of timber are laid between each pair of cross girders, resting on their bottom flanges, and planks are laid on these, forming a platform for the men to stand, or rather crouch, upon.

If the floor has been well made, and the cross girders truly squared, all the rivet holes in the floor will be quite concentric and true, and as the holes are short, only $\frac{3}{4}$ inch long—except the few at the cross girders where the rivets go through girder, flange, tee, and floor-plate, where they are $1\frac{1}{8}$ inch—the riveting can be got over very fast. A gang can put in, working fairly and where the holes are all right, about 60 rivets an hour. At 5 inches pitch, a plate 12 feet by 3 feet would have about 72 rivets in it. Then, $150 \times 72 = 10,800$ rivets, and $10,800 \div 60 = 180$ hours' work; or four gangs, could, if there were no other work to interrupt them, and working nine hours a day, rivet the floor in five days. This is never actually effected, for various reasons: nine hours cannot be worked in the three winter months, and various things make the time exceed this, even when the days are sufficiently long.

Care must be taken when laying the floor-plates to put those that have the holes cut in them for the gully-drains of the roadway in their proper places. Small round holes

are cut in other of the plates to receive small funnel-shaped pipes with perforated covers, standing so much above the plates as to bring them flush with the asphalte.

When the floor is all riveted down, the next job is to fix the cinder plates. These are 18 inches to 2 feet wide by $\frac{3}{8}$ inch thick, a continuous row of which, close butting to each other, is riveted to the latticing of the main girders, and whose lower edges rest on the floor angle-iron before described. They are called cinder plates because they serve to keep the cinders and refuse used for ballasting under the paving setts from falling through the latticing.

While they are being fixed the asphalters are at work, and the process needs a little description. First, the floor is swept quite clean and it must be perfectly dry; then men come with buckets of hot melted asphalte, and coarse small scrub brushes fixed to long handles; with these the floor is, as it were, painted with the asphalte. Other men follow them up with barrows of very coarse shingle or gravel, which is spread over the floor in sufficient thickness to make all a level surface up to tops of tee-irons and the curved floor plates; then asphalte is brought in buckets and poured over the shingle, through which it runs, cementing it all into one mass and making the surface very tolerably even. When this is hard, which quickly takes place, the surface is divided into spaces by laying down long narrow boards parallel to each other, then more melted asphalte is poured on within them and most carefully smoothed all over with, to all intents, smoothing-irons on long handles, making the whole floor surface smooth as a skating rink, and level or flush with the funnel drainpipes before mentioned. The cinder ballasting is carted on and spread over it, and the flags and curbing of the footpaths are put down, as well as any gas or water pipes required, and the gully drains are put in place and the roadway paved.

Some engineers put cast-iron coping saddles or pieces on the tops of the main girders, of a more or less ornamental character, generally of a less so. They are sometimes

fastened with small bolts, but occasionally retain their position merely by their own weight, and except for painting, the bridge is, as far as the ironwork is concerned, finished.

The bridge which is illustrated serves to unite the Pendleton and Broughton districts of Salford, and the new road which forms the approach to it is the connecting link which completes an almost direct line of communication from Pendleton to the northern districts of Manchester. In the design for the ironwork the stereotyped form of lattice girder has been to some extent departed from. In the top and bottom booms of the main girders, the plates which take the compression and the tensile strain are arranged vertically, in order that the strains may pass as directly as possible from the diagonals through the metal which is provided to resist them. It was found necessary to employ a certain amount of packing between the

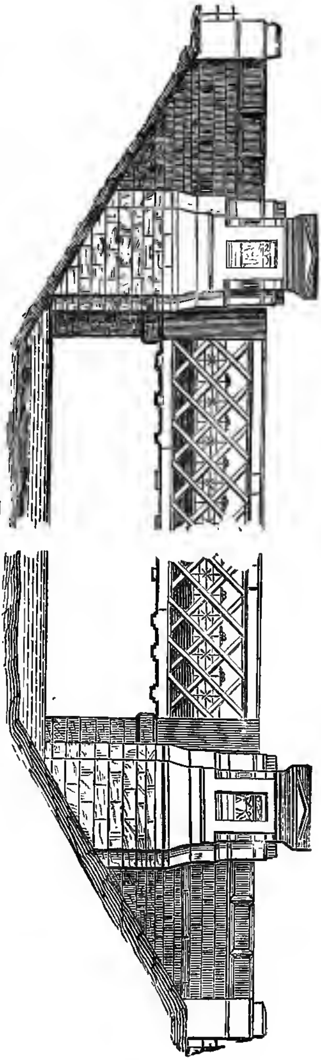


FIG. 35.

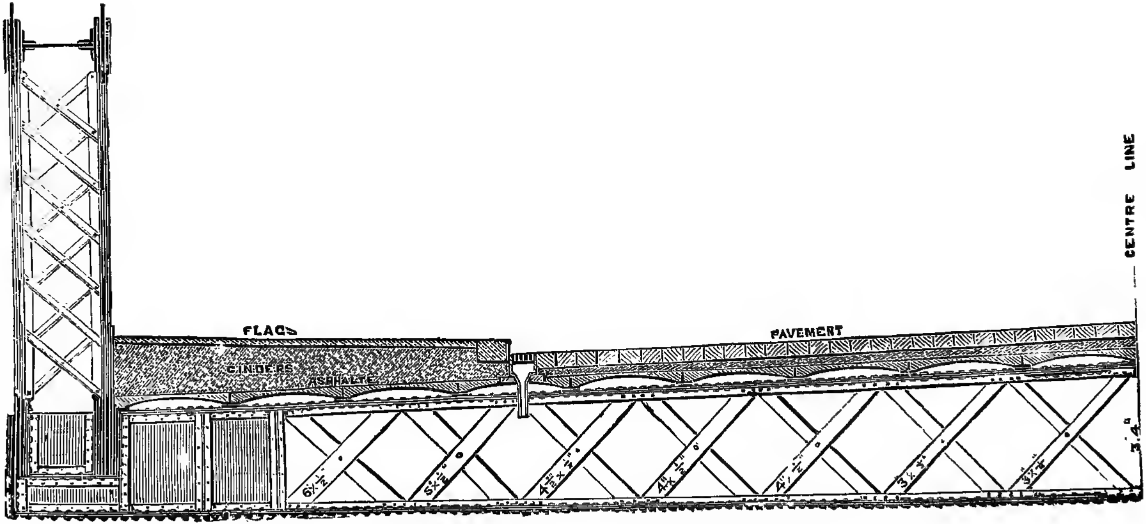


Fig. 36.—Half Transverse Section through Bridge.

points where the lattice bars are riveted to the web plates, but these packings have been made to serve the purpose of cover plates, and there is very little material in the girder work which is not usefully employed in resisting force of one kind or another.

The cross girders are attached to the main girders in such a manner that there can be no tendency to distort the main girder by bringing a greater strain to bear on the inside plates and bars than on those outside (see Fig. 31). A square gusset or knee-piece of plate is riveted between the web-plates of the main girder opposite to the end of each of the cross girders, as shown in the engraving, and the web of the cross girders is attached to this gusset by angle-iron and rivets, besides which the end plates are riveted strongly to the outside and inside web-plates of the main girders.

The roadway is constructed in the usual way of tee-iron placed parallel to the axis of the road, and resting on the cross girders, which have a camber on the upper side parallel to the curved section of the road. The platform is filled up to the level of the top of the tee-iron with asphalte, and over this is placed a layer of cinders as a bed for the paving setts which form the surface of the road.

The bridge has been designed to carry a live load of 100 lbs. to the square foot, the sections of the bars and plates being calculated with the usual margin of five times and four times the breaking strain for tension and compression respectively.

CHAPTER VII.

GENERAL PRINCIPLES—INFLUENCE OF TEMPERATURE—SECTION OF IRON —SPECIFICATIONS—EXTRACTS FROM MR. GRAHAM'S PAPER.

THIS book would not be complete without noticing other matter which, to avoid confusion, has not been mixed up with the purely executive matter just completed.

And first a few words may be said about general principles necessary to be kept in mind in designing iron bridges.

Mathematicians, if given certain fixed data, will in return give a skeleton diagram of every member of, say, such a bridge as the class just dealt with, as well as of more elaborate and complex structures, marking the tensile or compressive strain on each. Any competent engineer can in most cases do it. The working conditions of the bridge are in no sense fixed data, and even as the nigger could not count one pig of a drove, because he ran about so, so in like manner with a bridge. Conditions of wind, of temperature, of moving loads, and even undiscoverable flaws and defects of workmanship, import an element of uncertainty into the matter.

There are sundry practical points also outside the limits of theory that must be discerned and allowed for. Thus, American engineers assert that a certain amount of material, if concentrated in one member, will do more work than if the amount were divided between two or more members, and many American structures, either of wood or iron, reflect credit on their designers.

Theory should never be neglected in these matters, but it must be kept in its own place, and where common sense is interfered with by it, it must be put aside.

The action of the changing temperatures of the atmosphere does much to overthrow mere theory. Mr. Clarke, when speaking of the Britannia Tubular Bridge, observes: "Although the tubes offer so effectual a resistance to deflection by heavy weights or gales of wind, they are nevertheless extremely sensitive to changes of temperature, so much so that half an hour's sunshine has a much greater effect than the heaviest trains or the greatest storm; they are, in fact, in a state of perpetual motion." The same may be said of any iron bridge, especially of those over rivers, for the heat of the sun can beat with full effect upon the top members, heating and expanding them, while the lower members being in the shade, and the wind or light breeze, cooled by its proximity to the water, cools also the lower members, consequently the camber of the girders is constantly altering; and it is for this reason as much as for ornamental ones, that the cast-iron coping is sometimes put on to shield or screen it from the sun. In other cases it is painted white. The following figures, quoted from a paper on wrought-iron girder work, read by Mr. Graham Smith before the Liverpool Engineering Society in June, 1877, will give a good idea of the strain caused in ironwork by alterations of temperature:—

"If the difference between the extremes of temperature be assumed at 82° Fahr., or say between 20° above zero and 102° Fahr., and a change of 15° Fahr. be capable of inducing a strain of one ton per square inch on wrought iron, it follows that this variation of temperature, unless provided for, will induce a strain of 5·5 tons per square inch; but then this is a somewhat extreme supposition, for this reason, such extremes are never co-existent in any twenty-four hours, because the cold, ten degrees of frost, is of necessity only present in winter, and then the temperature in the sun might be taken at 40° Fahr., or a difference in any winter's day of but 18°, or a strain of little more than a ton. In summer the variation is occasionally more than this, say 36° between that at high and sunny noon,

when it might touch 100° Fahr., and the following or preceding morning at two. The extremes, too, act for but a part of the twenty-four hours, so it has not time to do much if any injury, especially if the non-conductive influence of the paint is to be counted for anything."

In practice in this country, according to Mr. G. Smith, an allowance of $\frac{7}{16}$ inch in every 100 feet is found sufficient. $\frac{7}{16}$ is $\frac{1}{2743}$ of 100 feet, and as iron within working limits stretches about $\frac{1}{10000}$ of its length for each ton strain per square inch, it follows that the strain caused in this country in ironwork, unless provision is made for expansion and contraction, will be 1 ton as 2,743 is to 10,000, or a little over $3\frac{1}{2}$ tons to the square inch.

It must not be forgotten, however, that differences of temperature act in two different ways on iron structures; one is, where some parts of the structure itself are of a different temperature to others of it, as in the case of the top and bottom flanges or members of a bridge girder. Mere alterations of weather heat will not affect it if it is all uniformly changed together. The second way is as regards the relationship of the structure to external structures, in such case as that of a girder resting upon two abutments. Here a girder 100 feet long in a frost may be 100 feet, and nearly half an inch long on a hot summer's day; in both cases, if the girder be of uniform temperature all over, there are few internal strains in it, but if one end is not left free to move, the bed-plate or masonry on which it rests will be cracked and displaced. It used to be an idea with some engineers that giving liberty to one end of a girder to move was a needless refinement, and in proof of this pointed to the friction rollers put under some which had rusted fast; but this does not at all prove that no movement took place. The author has been informed by an eye-witness that he had seen a very old iron bridge taken down whose girder ends rested on felt, put between it and the bearing plate, and that not the least trace of rust or corrosion was visible. Then again, concerning these strains, tie-rods or bracings

of all kinds may be carelessly screwed or cottered up so tightly as to greatly increase their ordinary legitimate load.

In designing an iron bridge, or, indeed, any iron structure of a kindred nature, when estimating the sizes of the sections to be used, three things must be kept in view :— First, the theoretical margin of safety to decide on; this is usually about 4½ to 1. Thus, if it is decided to use iron whose ultimate or breaking strength shall be 22 tons per square inch, then the Board of Trade rule for railway bridges is that the maximum working strain shall not exceed 5 tons to the square inch. The second is, to use all bars wide and thin rather than narrow and thick, because the rivet-holes can be kept farther apart and more of them can be got in; and, third, to carefully avoid adopting an unreasonably high margin of strength, as the doing so tends to weaken rather than strengthen the bridge, by loading it with a quantity of redundant iron and increasing also the difficulty of riveting it up soundly.

In fact, it may be laid down as a proposition that for a given iron structure, regarded from a constructive point of view, there is some particular quantity of iron which is best for it, and neither more nor less.

As for the durability of iron bridges it is to be feared they will never rival, say the Pyramids, in durability, owing to rust—and iron will do that, paint it never so wisely. There is, however, another source of decay existent, in what is called the fatigue of the metal. This is caused as follows. It was at one time considered that iron must be strained by a certain load before it took a permanent set, and this was termed its limit of elasticity. This may be determined in either of two ways; thus, in pure theory, such limit is that at which the elongation ceases to be in proportion to the additional strain; the other, and practical way, is to regard as limit that point up to which strain may be imposed, which however often repeated will not, after the first imposition, cause any further elongation.

For example: if a bar of iron be subjected to a strain of 10 tons and is thereby lengthened, say 3 per cent., and that when the load is removed it does not shrink to its former dimension but retains its new one, that is its permanent set. Well, if it is again subjected to the same strain a second time, and stretches no more, then the load is within the limit of elasticity; but if a further extension is perceptible then the load is beyond that limit, and iron should not, where possible to avoid it, be subjected to such a strain. Every care is taken to ensure this, and while the structure is new all is well; but as time, and rust, and the strains of expansion do their work, the limit is one day reached in some of the members. Then such members will begin to stretch more and more till, if not discovered in time, they give way. This is the way in which what may be termed the fatigue of the metal takes place.

A point of an essentially practical nature is, that in designing, care should be taken to introduce only sections that can be readily obtained in the iron market; it is very silly to design first and then find that this or that tee or angle-iron cannot be obtained. Here common sense must be heard. Young and enthusiastic engineers—boys—fancy they can design structures whose strains can be determined to any number of decimals, but they outgrow all that; scientific rules are indispensable, but science retires if absurdity comes to the front.

Sheets of sections of merchant irons of all forms in ordinary use are readily obtainable, and no drawing office ought to be without them, but even with them it is well, before working in any section shown on them into a design, to previously write an inquiry as to whether that section is in stock, or if the rolls will have to be shifted to roll it; an extra charge is sometimes made for changing rolls, unless the probable order will be a big one. The prices extra for sizes or lengths out of the ordinary are usually given with the sheets.

The influence exercised by the size of iron on economic

construction can be thus seen:—Take the case of a flat girder, say 65 feet span, to carry a load of 12 cwt. per foot run. Taking into consideration the economic practical as well as theoretical depth of such a girder, it will be found to be 5 feet 6 inches, but as plates more than 4 feet 6 inches wide are charged for at a higher rate, this modifies other considerations and fixes this as the proper depth of the girder. Short plates set vertically would not answer, because the tendency of the strain would be then across the grain or line of fibre of the iron. Some engineers would use Bowling or other equally expensive brand, for plans where there was much bending or twisting of the iron, but the author is of opinion that the more advisable way is to exclude such bends as far as possible from a design, it being often much better to use square corners and to make the plates or angles separate, to butt them close and rivet soundly; but at the same time, now that the practice of pressing the iron while hot into shape is in such general use, it can be bent thus without injury to the iron, and most accurately to form, in the press dies; therefore bends are less objectionable than where they had to be made by the smith's hammer.

Mr. G. Smith, in the paper before referred to, observes as regards testing iron:—"Ironmasters are averse to testing, to some extent." Mr. Smith said he was once advised by one of these gentlemen, of high standing, to exhibit his knowledge by simply specifying "best merchantable iron, and if from inspection it was found not to be good, it could then be tested."

The author has not met any such. The first lot of iron supplied under an ordinary specification is sometimes variable in quality, but the millowner can and will, by firm treatment, supply it of uniform quality. Contractors, to a great extent, estimate the quality of the work which will suffice, as well as the character of the engineer, by the style in which the specifications are got up. If the requirements are fair and just, and the drawings are done in a workmanlike manner, they will be careful in their move-

ments. If, on the other hand, the reverse of all this, they will put on a percentage to cover contingencies.

The following remarks are useful for inspectors :—

Engineers usually specify that the iron shall be tested at Mr. Kirkaldy's, or other independent testing-place, of which there are three or four available. There are Lloyd's proof-houses for cables and anchors, one at Netherton and one at Tipton, in Staffordshire, and the splendid testing machines of the Mersey Docks and Harbour Board. The Monk-bridge Iron Company have an excellent machine; so have Messrs. Galloway, of Manchester, at their Knott Mills Works. There is no difficulty in having the iron properly and impartially tested, and the method has been already described.

Specifications.

At the end of this volume will be found a copy of a specification for an iron lattice girder road bridge of considerable dimensions. It contains some defects. First, it would have been prudent if it contained on its first page a distinct statement that its terms would be strictly demanded and adhered to. No subsequent plea on the contractor's part that either he had not read this or that clause, and did not expect it to be exacted, would be accepted as an excuse.

The specification given contains a clause that all the iron delivered must be weighed on the Corporation or public weighing machine, and only the weights there found paid for. The precise object of weighing is not made apparent, and therefore may excite speculation in the mind of the reader. Obviously the actual must not materially differ from the engineer's estimated weights, because, if on the one hand the price tendered is a lump sum, as it usually is, then it is the contractor's interest to give "light" sections, to the detriment of the work. On the other hand, if the price tendered be a tonnage one, or at so much a ton, it is his interest to give "full" sections, thus enhancing the price to be paid. In either case, if the contractor is a sharp man he can "tip" the man rolling the plates and angles, who

will in return "roll full" or "roll bare," thus putting on or taking off a percentage of weight.

This stipulation is very unpractical; in most cases it would involve taking the iron a good deal out of the direct road from the canal or railway station to the site. The simple and practical method is to stipulate that authenticated copies of the carrier's weigh-bills be supplied to the engineer; this saves all trouble.

Another clause often difficult to carry out is that which demands that the whole of the parts shall be drilled while in the position they will actually occupy in the bridge. In some yards this possibly may be done, in others it actually is effected, while in others there are no appliances to hand for the purpose. In a certain yard in Scotland wrought-iron bridge piers 60 feet high, of pairs of girders connected by plate-iron arches, all the parts were clamped together and every hole was drilled, a machine made for the purpose being provided; but circumstances always alter cases. As a matter of fact, with such simple structures as those treated of in this work, there is no need for the process under review. Excellent work can be done, and is done every day, by template, but it needs patient, firm, and constant supervision, especially if done on "piece-work."

It is not generally wise for an engineer to give too many instructions as to the method to be pursued by the contractor in doing the work. He may suggest or recommend, but more than this will either be "wriggled out of," or else will cause extra cost. This is best left to the contractor. Besides, requirements of this sort risk the transference of responsibility from the contractor. Engineers, for example, unless under particular circumstances, should not require the iron to be obtained from particular firms, or made in a special manner; all this is for the contractor to look to. The iron must stand the tests—that is safeguard enough.

Reference has been made to the dispute clause in specifications. This gives absolute powers to the engineer; it is open to objection, however, and contractors bitterly resent

it. Men of all sorts and conditions like a power of appeal; this gives none, and if an engineer be unscrupulous he may half ruin a contractor, though the latter is generally very well able to take care of himself. The clause, as merely applying to the work specified for, is right enough, but frequently there are extras or alterations, and disputes arise as to their cost and what is to be paid for them. If these are small, mutual good sense and good feeling may, and often do, effect a settlement; but there are enough exceptions to make the clause distasteful to contractors.

The following is an extract from the report of the discussion on a paper "On Ironwork," by the author, before the Society of Engineers, London, in 1883, concerning the dispute clause:—

"Mr. W. J. Davey said that the author of the paper put his objections to the dispute clause on two grounds—first, the injustice of it, and then the illegality. With regard to the injustice much might be said in favour of the engineer. The withdrawal of the clause might to a certain extent do away with the independent position of the engineer, for whilst it was quite true that he was the appointed agent of his client, he also to some extent acted for the contractor, and had to see that the specification was adhered to by *both* parties to the contract. As the last speaker had said, the engineer must be the master of the situation. It had been implied that there was some doubt as to the legality of the dispute clause. It would no doubt be known to many of the gentlemen present that there was a well-known test case upon record in which a contractor had appealed from the decision of the engineer, and had taken the dispute clause through the whole of the courts, and it had been finally upheld, and after two years of dispute the disputed claim was referred back to the engineer for him to decide between the contractor and the other party to the contract. Therefore the dispute clause stood supreme as being recognised by the courts of law as being binding upon the parties to the contract."

The time or penal clause is usually a legal fiction. In works of any magnitude, or subject to any local circumstances such as preclude straightforward working, the time clause must of necessity be taken in a provisional sense. It is always difficult also to prove that delay is directly due to the inaction of a contractor, and here, as in other penal matters, a motive must probably be proved, and this is practically impossible; on the contrary, it is presumably to the contractor's interest to get the job done with all convenient speed.

Engineers usually specify that all holes are to be drilled, but a great deal may be said in favour of punched holes. The argument in favour of drilled holes is that a ring of iron round the punched hole is injured, as before observed. This is not supposed to be the case with steel, which is surely, if slowly, making its way into favour. Drilled holes do no injury to the adjacent parts of the plate; the work also is more refined. The faults of the drill are that it is much more expensive; some authorities put it at £1 a ton more. It is so favourable to the iron that the most inferior rubbish can be drilled, and no sign apparent to show the inferiority.

The arguments against punching having been given, those in its favour may be inferred also. Those are, less cost, bad stuff will not punch without "telling tales." Iron that will drill and "make no sign" will not bear punching at all. Besides this, punching is much more expeditious than drilling.

Some years ago, M. Barba, a constructor in the French navy, found, by experiments with mild steel plates, that the injury done by punching holes in it was confined to a ring only $\frac{1}{25}$ inch wide round the hole. No exact hard and fast rule can well be laid down about this matter; one method is best in some cases, the other in others.

The following is quoted from Mr. G. Smith's paper before referred to:—

"The stiffeners to the web of a plate girder, if splayed

out clear of the angle irons will cost about fifty per cent. less for smithing than when made to fit close round them, and answer their purpose equally well. This class of stiffener cannot be adopted where the flanges are too narrow to admit of four rows of rivets; but when the flanges are of sufficient width to admit four rivets at one cross section, but require only two for their construction, the additional rivets can generally be put in without taking from the strength of the girder. The flanges of plate girders usually possess an excess of strength at points not very far distant from each other, owing to the unvarying thickness of the plates; it is at these points that the stiffeners should be put in, if they can be so arranged as to be equidistant. If this cannot be effected, the cost of making extra templates, and the trouble caused during the construction, will more than counterbalance any economy to be derived by taking advantage of this fact.

"The position of the rivets, their diameter and pitch, should be carefully considered, as it is on them that the whole strength of the structure depends. No amount of extra metal in the body of a tie can compensate for a badly constructed joint. Carelessness or ignorance of these small things at once indicates the amateur designer, who is often led astray by the facility with which he can ornament his drawings with these little circles or red crosses.

"Many engineers specify for every class of work that all rivet holes are to be drilled, so increasing the cost of the work by not less than £1 per ton.

"This is a mistake, for experiment proves that with good ordinary iron the damaging effect of the punch is small.

"The question whether to employ punched or drilled holes ought to be a matter to be decided by the engineer in each particular instance. If a number of plates are to be riveted together, or an intricate junction made, the drilled holes will be more accurate unless great care is

exercised by first-class men at the punching machine When a simple plate and angle iron are to be put together, the balance of strength in favour of drilling is not sufficient to sanction the extra cost.

"With punched work some idea of the quality of each angle, plate, and bar may be formed by examining their respective punchings, as already pointed out. A want of proper welding on the laminæ of the iron may also sometimes be detected when punching. It is difficult to punch near the edge of very bad iron, but a drill may be put through almost any rubbish.

"In the early days of engineering it was a common practice to make things strong enough, on the supposition that a structure tested with something more than its working load would be quite safe, which has already been shown to be erroneous. Still, on the completion of the structure, and before it is painted, it should be tested with a proof-load and the deflection taken. This is simply a test of workmanship which ought only to be carried out in conjunction with the tests of materials. Hard brittle iron under this test may appear superior to a better and more desirable quality, and a part of the structure may be on the point of breaking and yet not yield sufficiently to materially alter the deflection.

"Carrying out tests will involve an additional expense, but it is small, and against it the engineer may set the gain of esteem on the part of every honest contractor, and the satisfaction of knowing that he is obtaining good materials and workmanship. When it is considered that 'iron is not always iron, for sometimes it is simply rubbish,' tests are absolutely necessary to enable an engineer to state with confidence what is the maximum safe working load of a structure. When dealing with constructions subject to much vibration or great change of stress, iron, like Portland cement, becomes a dangerous material in the hands of those ignorant of its qualities.

"If an iron structure is well designed, erected, and

taken care of, there can be no reason why the term 'life of ironwork' should not become obsolete. Iron embedded in concrete has been found at the expiration of years as free from decay as on the day of its manufacture. It is said, in fact, that water has no action on iron at the ordinary atmospheric temperatures, provided air be excluded. The usual means resorted to to effect this is by giving the ironwork a succession of coats of paint, and the limits of decay by corrosion are entirely governed by the efficient state in which this paint is maintained.

"Keeping these facts in view, the ironwork should be designed free of access to all parts for periodical examination. Painting the internal surfaces of box girders and cellular flanges has always been a difficult and costly operation. It is therefore fortunate that experience and science have demonstrated that such forms of construction are seldom necessary in modern practice. They may almost be considered as types of a bygone age, to slavishly imitate which, in many cases, shows ignorance of the principles and practice of modern girder work.

"The paints used for ironwork are of every description, name, and quality. The usual varieties employed for preserving it against corrosion may be divided into lead, iron, oxide, silicate, and tar paints. Differences of opinion exist as to the relative merits of the first three descriptions, but the experience of several foremen painters connected with establishments in this town, whom the author has interviewed, is decidedly in favour of lead paints when of good quality, and mixed with good oil without spirits. Unfortunately there are no reliable practical tests to ensure good materials alone being used; consequently both the colours and the oils are often inferior in quality and much adulterated. For these reasons, and on account of cheapness, iron oxide paints are by some preferred.

"A little white lead mixed with the red makes it go farther, and easier to work into corners. If the first coats are put on with pure red lead, owing to its weight it is

liable to run; but the last coat should consist of red lead alone.

"The tar paints are more often used for ironwork which is not to be seen, such as water-pipes, floor-plates of bridges, and girders which are to be built into masonry or brickwork. It is cheap, and answers well for such purposes and for sea work, as it is said not to foul so readily as lead or other paints of a finer description.

"A good rough paint of this class may be made by heating ordinary coal tar, and mixing with it finely-sifted slaked lime, in the proportion of between half a pound and a pound of lime to a gallon of tar, adding sufficient naphtha to render it of a convenient consistency for laying on. This composition should be applied while hot, but care should be taken not to make it too hot, nor to keep it over the fire too long, or it will lose its essential oils, and be reduced to a substance in all points resembling pitch. Some positions admit of the paint being sanded, in which case it should be done, as it adds to its durability.

"Before painting ironwork it is usual to give it a coat of boiled linseed oil, applied hot; this forms a kind of varnish and is an excellent preparation for the after coats of paint. Opinions differ as to when the coat of oil should be applied. Some engineers specify that the iron shall be brushed over or dipped in oil while hot from the rolls. The efficacy of this method is doubtful, as the iron in undergoing its workshop manipulation is subject to rough treatment, and portions of its surface are sure to become exposed. Others specify that the iron shall be brushed over with hot oil just previous to the various portions being put together. This answers well for ordinary work, as by the time it has gone through the workshops the blue scales have to some extent been knocked off.

"These blue scales are in a greater or less degree inseparable from the manufacture of the iron, but it is very important that they should be removed by some means or other before the paint is put on, for if not, in a short time

they will peel off and bring the paint along with them. The best way to guard against this is to have the ironwork put together in the yard and tested previous to either oil or paint being put upon it. A slight rust will form over the whole surface of the work, which will cause the blue scales to fall off. The rust should then be scraped off and the whole of the work rubbed down, which will render the surface peculiarly fitted for receiving the after coats of oil and paint. The oil should follow up, as closely as possible, the man cleaning the work. It is almost needless to point out that the efficiency of this method entirely depends upon the thoroughness with which it is done, and no engineer is justified in specifying it unless he purposes putting an inspector to see that it is properly performed.

"It may be well to point out that for foreign up-country work, too much care cannot be exercised to insure that it is properly painted in the first instance.

"In conclusion, the author will only briefly refer to Professor Barff's recently discovered method of coating iron with magnetic or black oxide. This he effects by subjecting it to st am at a high temperature of about 1,200° Fahr. for six or seven hours. It is said that iron so treated will resist a rasp, and bear any amount of exposure to weather without showing any signs of corrosion."

CHAPTER VIII.

DUTIES OF THE INSPECTOR—EXAMPLES OF SPECIFICATIONS.

The inspector, resident engineer, or clerk of works, as that official is indifferently designated, has an extremely responsible and somewhat difficult post. His business is to see that the specification is adhered to. In theory this is simple enough, and where the contractor is an upright man with a good reputation, which he means to keep, simple also in practice. A good inspector is a man not too young, old enough to inspire respect, with a thorough practical knowledge of his business; he must have considerable strength of mind, plenty of tact, and endless patience and command of himself. He must also understand human nature and possess great discernment. He has very troublesome cards to play: he has to deal with his chief on one hand, and with the contractor, his executive staff, and all the men on his job on the other; he must know when and whom to admonish or reprimand. As has been before observed, respectable, honourable contractors—and there are very many such—like to have an inspector constantly looking after a job; it saves them much trouble and even some responsibility. They like to have him if he is the right sort, one possessed of the qualities enumerated above, who is dignified without being supercilious, and who shows that he knows good work when he sees it. He ought to do his utmost to carry on his duties without being offensive or unreasonable, or disposed to split hairs about trifles. This last is a great mistake. If he makes a great fuss about petty matters he will make himself contemptible, and provoke the very hoodwinking and sharp practice he is there

to prevent. His manner should be affable and courteous to every one. He must also be rigidly just. Different men have different methods, but the following outline may form some guide :—

When the chief engineer receives a report from the contractor that the first lot of iron for the work has been received from the mill, he either goes in person, taking his inspector with him to introduce to the contractor, and marks certain samples and leaves orders for their preparation for testing, or else he gives a letter of introduction to his inspector and sends him. The latter goes to the works and presents his letter; he will be received politely, and if offered, as some are, a glass of sherry or a cigar he should accept, unless he be a teetotaler or a non-smoker, otherwise his refusal is open to the interpretation that he is there as a foe, a broker's man in charge, an antagonist; such an impression he should carefully avoid. He will be taken and shown round the works, and introduced to the manager, who in turn will introduce him to the foreman, whom he must inspire with respect. He ought not to be either too distant or too familiar with the men ; if he is the former he irritates them, and excites an animosity which shows itself in silent but steady obstruction. This is greatly to be deprecated, as they have numerous ways of making things unpleasant for him. and imposing upon him. On the other hand, over-familiarity brings him into contempt.

A judicious "tip" to the foreman, or a leading hand, is always well-spent money; he will receive the greatest attention, he will be aided and helped in numerous ways by respectable and skilled workmen—plates will be shifted for him, a ladder, tools, a foreman found, and many other little things done for him.

An inspector usually requires no tools or instruments save a note-book, a small folding rule, and his private stamp. This is a steel marker cut with some device not in common use, such as a Greek letter or the like. A rule, or slip, $4\frac{1}{2}$ or 5 inches long and about $1\frac{1}{2}$ inch wide. Crosswise in

this at its centre should be a sliding-piece, which when shut in leaves the rule parallel on both sides, but which can be pushed out sideways (see sketch, Fig. 37). Its use is to measure the snap-ends of the finished rivets. Fig. 37 shows how it is used. The plate S is divided into sixteenths of an inch. Now, if certain rivets are to be snapped to a depth of $\frac{3}{8}$ inch, or from A to B, it is necessary for the inspector only to draw out the slide a little more than the required distance, and then, setting its end against the plate between the rivets, press the rule itself in till it rests on both rivet tops. An examination of the mark opposite end of slide T will at once show depth of "snaps." The reason the rule should be more than 4 inches long is that rivets in general girder work are "pitched" 4 inches centre to centre, and thus the rule will "bridge" or span them.

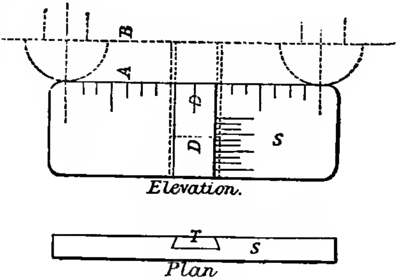


FIG. 37.

Another little tool he will find of great service is a thing like sketch; it may be called a rivet-hole gauge. Fig. 38 shows one form of it, but it may be varied in the method of making it, as, for example, it might be made with a hinge or pivot in the centre, so as to fold up to half the length for greater convenience in the pocket. It has a very important use. It is essential to the soundness of the work that all the adjoining parts, such as plate-edges and angle-irons, should butt close up, as tight as they can go,

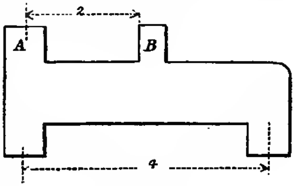


FIG. 38.

and the inspector ought to provide himself with a strip of thin crinoline steel with a smooth and level end, wherewith to test the plate joints. It is not much use, however, because it can only be applied when the holes are drilled and all ready for riveting, and even if he did get a joint so wide that he could get it in, he would find it difficult to induce or compel the contractor to remove the plate and put in a new one. Neither need it happen, as the rivet holes are 4 inches pitch, and of course the joint of a pair of plates is midway between them. All that is needed to secure close joints is to make sure the rivet hole centres are exactly 2 inches from planed end of plate. The gauge shown at Fig. 38 has at one side two projections, A B, and from next side of B to centre of A is exactly 2 inches. These projections are marked or stamped $\frac{7}{8}$ inch to denote they are for rivets that size, but as the holes are, for all rivets above $\frac{1}{2}$ inch diameter, $\frac{1}{16}$ inch larger than the rivets going into them, these projections are $\frac{15}{16}$ inch broad. Now as the centre of the hole must be just 2 inches from end of plate, and as the distance from the *centre* of one projection to the nearest side of the other is likewise 2 inches, it follows that if the gauge is applied to a plate end, one projection just fitting into the hole and the other passing tightly over end of plate, that any two plates drilled thus, and having a cover plate at each side pierced with holes same size and 4 inch pitch, that the two plates must have their respective ends brought in close contact before the rivet holes will be all concentric. The projections at other side are 4 inches apart centre to centre, and can be used to gauge rivet holes in the bodies of the plates.

He will be shown the plates and other iron delivered, and will do well to have a few of them turned over in order that he may examine them for flaws, cracks, or blisters, or other defects. If he gets some of the plates set up on edges, or better still, slung from one of the plate cranes, and strikes them with a hammer, he will, if at all experienced as a man should be to hold such a position, know by

the ring if it be cracked or sound. As a matter of sound practice, however, he had better not do this very exactly or formally, because after all he may be deceived, and might with very sharp contractors, or men who had very sore feelings against engineers, find it difficult to make them "turn out" a plate simply because it did not ring sound. On the other hand he might, by over formality of examination at this stage, run the risk of relieving the contractor of any further responsibility for the soundness of the plates, and above all other things an inspector must most carefully avoid two things: First, relieving a contractor of any measure of his just responsibility; second, to carefully avoid giving unreasonable or capricious orders, or any that he cannot enforce. The first is extremely improper, and will most certainly and rightly get him into trouble with his chief. The second will bring him into contempt with every one, from the head of the firm down to the smallest boy in the yard.

The whole efficient conduct of his duties depends on his ability to inspire and retain respect. Neither should he display a bombastic or overbearing manner. He should be simple and courteous, slow to find fault, willing to talk things "over a bit," but as firm as adamant on all occasions of importance. If tests are being made by his or his chief's consent in a machine of the contractor's own, and they are a well-reputed, respectable firm, possessing a machine by a well-known maker, there is no need for him to measure the centres of the levers or the diameter of the ram. The weights are stamped, the steel-yard is figured. In fact, testing machines are nothing more than elaborate weighing machines, and he ought to have no difficulty in satisfying himself as to the integrity of the test strains applied. Few contractors have a testing machine of their own, but many can have the use of one, and where a good one is available its use saves much time. The author has had a good deal to do with contractors for ironwork, and though he has met some "sharp" hands, the

far greater number have been till their death, or those living, are as upright, honourable men as could be met with. In proof of this the author may cite one case where, desiring to test some iron sent in during the course of the work, he was asked to test it in the yard machine. He assented, and having first taken steps to satisfy himself that the machine, which was an old one, was reliable, he tested the iron, which failed to come up to the standard. The millowner supplying the plates was communicated with and came, and the author allowed him to go and select plates himself, have test pieces cut and prepared, and when ready, to test for himself. This was done, and they were found wanting, and all that delivery therefore had to be rejected and taken back. Of course if the millowner had shown his tests to be good, the author would have sent samples away to some independent authority to settle the question, but as it was he convinced the contractor of the truth of his objection, and the millowner also, but this proved the honesty of intention of the contractor at all events, and, in the author's opinion, of the millowner also.

To return to the cracks and blemishes matter. The plates have to go through so many handlings in working, drilling, and planing, &c., that long before going to the site any defects existing are sure to be discovered in time.

The cross-girders are nearly always finished in the yard, riveted up complete; therefore the inspector must give particular attention to inform every one concerned, from the head of the firm on down through the manager, the foreman, leading man, and all others, that they may put together, and service-bolt as much as they like, but no riveting must be done till he has seen the work first. It will not suffice to tell one person or two persons, *every one concerned* must be told. Otherwise when he next comes he finds a lot of work riveted up, and he knows little of how the parts have gone together, and he cannot very well have it all cut to pieces again. The frequency of his visits must

depend a good deal on the state of the work. Sometimes he will need to be present nearly every day; other times twice, or even once a week will suffice. He must, however, let the contractors know clearly that he is at their call at any time. This is very important, because contractors seldom hurry themselves, and if there is any "trouble" about the work not being finished up to time the contractor may, and often does, lay the responsibility on the shoulders of the inspector. This the latter must carefully guard against.

When the bolted up work is shown him he must examine it all over, especially the joints of the plates and the rivet-holes. The former ought to be close butt, the latter all truly concentric. This can be ascertained best by putting in the finger and feeling if all is even. If he is satisfied, he allows the work to be riveted up. But if the joints or holes are wrong he must call the attention of the "ganger," or man immediately in charge. Perhaps the work has not been properly drawn into place, and the driving of a couple of barrel or parallel drifts will bring everything quite true. Of course, if the work is really bad, all the faulty parts must be rejected; but if the inspector knows his business well and attends to it, he will never, as the saying is, let things come to that pass. As has been already said, if all the preliminary steps have been correctly taken, the thing must come together right. The rivets for the work must be a proper fit to the holes, and the inspector must see that they are. Hole $\frac{1}{16}$ larger than rivet is the general rule.

Girders are now constantly riveted by a "Tweddle" or other riveting machine, and care must be taken that the pressure is not so great closing the rivets as to bulge or split the angle iron or plate, which is the danger with all riveting machines, unless they are fitted with a safety relief valve which keeps the pressure within certain limits.

The rivets ought to be tested in the manner already described, but appended is a copy of the rivet clause of a specification:—

Bombay, Baroda, and Central Indian Railway Company.

Specification for Wrought Iron Girder Bridges.

Drawing No. 2.

The work required under this specification comprises the construction, supply, and delivery at one or more ports named in the tender, or in Bombay, of the whole of the iron work for sixteen-plate girder spans of 15 feet in total length, together with all nuts and bolts required to complete the erection of the work in India, with an addition of 10 per cent. for waste. Quality of the iron is to be such as will stand the following tests :—

	Tons.		Contraction per cent.
Round and square bars, and flat bars under 5 in. wide	24	..	20
Angle bars and T bars, and flat bars 5 in. wide and upward	22	..	15
Plates	21	..	10
Plate across the grain	18	..	5

The rivet iron must be of such a quality that any rivet made from it will stand the following tests without showing signs of failure :—Bend double upon itself whilst cold; bend double upon itself whilst red hot; the shank being nicked whilst cold and bent double, showing the fibre of the iron to be of good quality; flattening down the head whilst red hot until its diameter is equal to $2\frac{1}{2}$ times that of the shank without showing any signs of cracking at the edges; punching through the shank when at a red heat, with a taper punch, a round hole the diameter of the rivet, without showing signs of cracking or splitting.

It is the practice of some engineers to test each cross girder before it leaves the yard by supporting it on bearings at each end, and loading it either all over as "distributed load" or in the centre, and measuring the amount of deflection for a given load. But if the iron has been previously tested the author sees no good purpose to serve in

the present day when such work is so thoroughly understood, that if design, materials, and workmanship are right the load test is not needed, unless, perhaps, for railway bridges, but at all events not for road ones.

Lastly, the inspector ought to keep a diary and record in it with some degree of accuracy all that has passed during his visit that day to the yard, and all the verbal orders he has given. He ought to keep this carefully written up. It might have to be produced in a court of law and he swear to it. Now if he lets days elapse between a visit and writing the record of it, how can he fairly swear he has correctly written down what passed? It ought to be done that evening if possible, or at furthest next day.

He ought to send a formal report once a fortnight to his chief, but he ought carefully to refrain from making petty complaints of the contractors or their staff. His chief has more important things to think of, and will not think any the better of his capacity for his duties if he shows he cannot carry on the work properly himself. His chief may think, perhaps, he ought to take some notice. If he be the engineer to some public body he may have to read the letter to his committee, and they may get some fad that there is a screw loose somewhere; letters are written to the contractors, and there is "trouble" all round; then ever after that the inspector is regarded with distrust as a vexatious mischief-maker. The proper course of action if things are not going quite right is clearly shown in the greatest of all books—the Bible. In that it will be found, "If thou have a fault against a brother, tell him his fault between thee and him alone; if he hear thee, thou hast saved thy brother; but if he hear thee not, tell it to him before one or two witnesses; if he hear not them, tell it unto the church; and if he hear not the church, let him be unto thee as an heathen man and a reprobate."

In the same way, if the inspector sees work being badly done, let him caution the leading man in charge. If he attend, well and good; if not the foreman must be told;

if that fail, the manager; if that fail, then the head of the firm must be informed; he will put things right very soon; but if he takes no action, and things go on badly, the inspector must warn him that the thing must be formally reported at headquarters. No complaints ought ever to be made to a chief without a preliminary caution to the contractor, who will be thereby inspired with respect for the inspector. If little hitches or oversights occur or are discovered on the drawings, the inspector ought to quietly consult over them with the foreman or manager, and devise a remedy without "worrying" his chief about such things. He is paid for that as much as for anything else; therefore, let him do it.

Let him have his eye everywhere, his observation ever in action; let him listen much and speak little. His visits ought not to be made at regular set times, but so much at random as to leave no room for previous preparation. Not, indeed, that there can be much in any case, if he have the work and the men well in hand.

The author concludes with these words to inspectors:—

"Prove all things, hold fast to that which is good." "Let all things be done decently and in order."

CHAPTER IX.

ON RIVETING AND CAST IRON.*

IT is sometimes stated that, owing to the contraction of rivets in cooling, the plates are brought into such close contact that the friction between them is sufficient to withstand the working strain without any shearing action coming upon the rivets. This is an important point, and one which has been often discussed; it may be well, therefore, to pass in review the various opinions on the question. Mr. Edwin Clarke, in his work on the "Britannia and Conway Tubular Bridges," makes the following observations:—

"The contraction of a wrought-iron rod in cooling is about equivalent to $\frac{1}{10000}$th of its length, for a decrease of temperature of 15° Fahr., and the strain thus induced is about one ton for every square inch of sectional area in the bar. Thus, if a rivet one inch in section were closed at a temperature of 900°, it would in cooling decrease in length $\frac{60}{10000}$ths of its length, and if its elasticity and strength remained perfect would produce a tension of 60 tons. The ultimate strength of rivet iron, however, being only 24 tons, the rivet would in cooling be permanently elongated, and would continue when cool to exert a tension of 24 tons, provided its elasticity remained uninjured by the strain. Thus, if the rivets were not in contact with the plates, excepting at the head and tail, the plates would be held together by a pressure of 24 tons, and this friction would have to be overcome before the rivet came into action as a mere pin."

In order to ascertain how far this theory holds in practice, Mr. Clarke conducted some experiments, from which the following are taken:—

* From "The Construction of Iron Girder Work," by Mr. Graham Smith.

Three $\frac{5}{8}$-inch plates were riveted together with one rivet in a manner similar to a chain, the hole in the centre plate being oval and considerably larger than the $\frac{7}{8}$-inch rivet; a weight of 5·59 tons was attached to the centre plate before it slipped, which it did abruptly.

The experiment was repeated with $\frac{1}{2}$-inch washers placed on each side of the outer bars, so making the shank of the rivet $2\frac{7}{8}$ inches in length; under these circumstances 4·47 tons caused the plate to slide.

The rivet in the last case being assumed to be faulty, the same experiment was repeated, and the plates sustained 7·94 tons before they slipped.

"In the next experiment a $\frac{7}{8}$-inch rivet was inserted through two $\frac{5}{16}$ plates, with large holes, with a $\frac{5}{16}$ washer on each side next the rivet head. This combination supported 4·73 tons before it gave way."

After going fully into the matter, Mr. Clarke infers that the Britannia tubes would not deflect more than they do at present, even supposing all the holes to be too large for the rivets. He also points out that rust must be entirely superficial, the close union of the plates preventing any internal oxidation. His remarks are concluded as follows:—

"Thus also by judicious riveting the friction may in many cases be nearly sufficient to counterbalance the weakening of the plate from the punching of the holes; so that a riveted joint may be nearly equal in strength to the solid plates united."

Mr. Fairbairn, in his "Useful Information for Engineers," says:—

"From these facts it is evident that the rivets cannot add to the strength of the plate, their object being to keep the two surfaces of the lap in contact, and being headed on both sides, the plates are brought into very close union by the contraction or cooling of the rivets after they are closed. It may be said that the pressure or adhesion of the two surfaces of the plates would add to the strength. But this is not found to be the case to any great extent,

as in almost every instance the experiments indicate the resistance to be in the ratio of their sectional area, or nearly so."

More recently, Mr. E. J. Reed, late chief constructor of the navy, has had some experiments carried out closely resembling shipbuilding work. They are here given as recorded in his valuable work on "Shipbuilding in Iron and Steel."

"In this case three plates were united by what is known as a chain-joint; that is, the ends of the two outer plates overlapped the end of the middle plate. The connection of the plates was made by three rivets passing through the lap, the rivet-holes in the outer plates being filled by the rivets; but the bearing surface of the holes in the middle plate were slotted out. It will thus be obvious that when a tensile strain was brought upon the middle plate, the amount of the friction could be measured by the force just able to produce a sliding motion. The breadth of the lap was three diameters, the rivets were a diameter clear of the edges of the plates, and the pitch was four diameters. There were two sets of experiments made with iron plates and rivets, and in each set of two, experiments were made with rivets having heads and points snap-headed; two others with rivets having pan-heads and conical points; and the remaining two with rivets having countersunk heads and points. The experiments were made in duplicate, in order to reduce the chance of error. The first set of experiments was made with $\frac{1}{2}$-inch plates, $8\frac{1}{4}$ inches wide, the rivets being $\frac{3}{4}$-inch. The results were as follows:—

Description of Rivet.	Friction per Rivet.		
	1st Experiment.	2nd Experiment.	Mean.
	Tons.	Tons.	Tons.
Snap-heads and points . .	5·14	4·21	4·67
Pan-heads and conical points .	5·26	4·81	5·00
Countersunk heads and points .	4·56	3·74	4·15
Mean of the three	..	..	4·61

The second set of experiments was made with plates 11 inches wide and $\frac{7}{8}$ inch thick, the rivets used being 1 inch in diameter. The following results were obtained under the above-stated conditions of pitch of rivets, lap, &c.:—

Description of Rivet.	Friction per Rivet.		
	1st Experiment.	2nd Experiment.	Mean.
	Tons.	Tons.	Tons.
Snap-heads and points . .	5·84	5·61	5·7
Pan-heads and conical points .	6·87	7·24	7·0
Countersunk heads and points .	4·56	4·09	4·3
Mean of the three . . .	..	..	5·6

"In addition to these experiments with iron plates and rivets, two other sets of experiments were made with steel plates and rivets of exactly the same dimensions as those used in the former experiments, the pitch of rivets, breadth of lap, &c., being in each case identical with those previously given. With $\frac{1}{2}$-inch plates and $\frac{3}{4}$-inch rivets, the results obtained were as follows:—

Description of Rivet.	Friction per Rivet.		
	1st Experiment.	2nd Experiment.	Mean.
	Tons.	Tons.	Tons.
Snap-heads and points . .	3 86	4·09	3·98
Pan-heads and conical points .	4·79	4·79	4·79
Countersunk heads and points .	3·63	3·43	3·53
Mean of the three . . .	..	..	4·1

"With $\frac{7}{8}$-inch plates and 1-inch rivets, the following results were obtained:—

Description of Rivet.	Friction per Rivet.		
	1st Experiment.	2nd Experiment.	Mean.
	Tons.	Tons.	Tons.
Snap-heads and points . .	6·43	5·49	5·96
Pan-heads and conical points .	5·49	none made	5·49
Countersunk heads and points .	5·14	4·91	5·02
Mean of the three . . .	..	..	5·49

"It thus appears that rivets with pan-heads and conical points have the advantage over both the other descriptions of riveting. The only exception to this is found in the second set of experiments with steel plates and rivets; but as only one experiment was made the result cannot be relied on. It also becomes evident that countersunk riveting causes much less friction than the other systems. On comparison it will be seen that in nearly all cases steel plates and rivets give less friction than iron, the only exception being the cases of rivets with snap-heads and points, and those with countersunk heads and points, in the second set of experiments. The former of these exceptions is scarcely worth notice, as the difference is so small. The use of larger rivets with the same pitch, &c., gives an increase in the friction, but no law of increase appears to be conformed to.

"Although these experiments do not give any definite idea of the probable amount of friction which would result from the use of rivets having different diameters and pitch, they yet serve to show how much the strength of a riveted joint is increased by the contraction of the rivets."

Mr. Reed, at a more advanced stage of his investigation on this point, says:—

"It would consequently be improper to arrange the fastenings of a wrought-iron structure on the assumption that the shearing strengths of the rivets (determined by experiments on rivet bars) and the friction of the surfaces might be treated as acting conjointly but independently. In the investigations on riveted work which are given in this chapter we shall, therefore, assume that friction is included in the values which are employed for the shearing strength of the rivets."

Mr. Reed considers that his views as here expressed agree with those of Mr. Fairbairn before given. Still the author* thinks that there is some disparity in the views held by the eminent authorities named. If this were not so, he would certainly hesitate to express the opinion that, unless

* Mr. Graham Smith.

in very superior work, rules in regard to the friction between the plates deduced from experiments, will prove very fallacious in practice. Rivets frequently not only do not fill the holes, but they are in addition sometimes positively loose. Under any circumstances it may safely be assumed that there are few rivets in any work which exert a holding-together strain of 24 tons per square inch. Even should such be the case on the completion of the construction of the work, it would not be of long duration. A very small additional strain will cause iron to considerably elongate, when previously under a strain nearly approaching its breaking point; and the smallest possible additional set will be sufficient to do away with any advantages to be obtained by the contraction of a rivet in cooling. Although it is not here the intention to imply that the frictional resistance of the plates will not add a certain amount of strength to a joint, still the author is of opinion that with vibration any additional strength caused by this resistance will be destroyed, and that therefore the old rule should be adhered to of making the shearing area of the rivets on one side of the butt equal to the effective area of the plates in tension. The shearing strength of a rivet not being equal to the bar from which it is made, a few rivets over and above the number thus deduced will in the author's opinion neither do any harm nor add greatly to the cost of the structure.*

While on this question it may be well to touch briefly upon the kindred subject of cast iron. The proper design and relative proportions of the flanges of an ordinary cast-iron girder have been repeatedly subject to experimental investigation. The results obtained are so familiar to every engineering student, being given in full in most engineering works of a compendium nature, that it will here suffice to remark that opinions differ as to the relative areas of the top and bottom flanges. There are, nevertheless, only a few engineers and scientific men who will argue that the area of the top flange need be greater than

* I agree with Mr. Smith.—H. W. PENDRED.

one-fourth of that of the bottom flange, and as this is the proportion employed in many large works recently constructed by our leading engineers, the author feels that he will not err if he advocate the adoption of this ratio in future practice. Having arrived at the relative areas of the flanges, the next question is to decide upon the proper area of the bottom flange. With a dead load cast iron may be subjected in actual working to a tensile strain of $1\frac{1}{2}$ tons per square inch, but with a live load it is advisable not to exceed a calculated strain of $1\frac{1}{4}$ tons per square inch. The strain on the flanges having been calculated, they may now be designed, and so formed as to suit themselves to outside considerations as well as exigencies of a practical nature. In designing the top flange, with a view of adding to its lateral stiffness, it should be made as wide as the amount of metal in it will allow, of course bearing in mind that a certain minimum thickness is required for foundry operations. Where the girders support jack arches and are concreted over the top, or in fact in any position in which lateral movement of the girder is impossible, width of flange is not so necessary. [When dealing with a girder continuous over its supports, the top flange will be in tension over these points, and consequently matters in this case will be entirely reversed.] The web now alone remains to be considered. Its dimensions are governed entirely by considerations of a purely practical nature. If only made of sufficient thickness to resist the strains brought upon it, it could not be cast owing to the small proportion which its mass would bear to that of the flanges. If the thickness of the web at the top be made the same as that of the top flange, and gradually increased downwards to about the same thickness as the bottom flange, and the remarks which have been previously made regarding the area and design of the flanges be borne in mind, the resulting section will, in the author's opinion, meet constructional requirements and the wishes of the ironfounder.

It is at once evident that before an engineer is qualified

to design cast-iron work, he should to some extent be familiar with the details of both pattern-making and moulding. Without such qualifications he is apt to make his castings expensive, and the author has even seen designs sent out which defied the skill of an ordinary foreman moulder simply through the man who made them not knowing how "boxes" and "cores" are manipulated. It should also be remembered that small masses of iron cool more quickly than large masses, and that therefore portions of small dimensions will consolidate while the adjacent portions of larger dimensions remain in a fluid state. This irregularity in cooling will produce initial strains on the iron which may distort or even cause the destruction of the casting. Care should, therefore, be taken both in making the designs and in making the castings in the foundry to insure the iron cooling as evenly as possible. Unless in the case of absolute fracture or much distortion, initial strains give no visible sign of their existence, and are, therefore, all the more dangerous.

When referring to the tensile strains to be imposed per square inch of section, it was of course inferred that proper precautions would be taken to secure a good ordinary quality of iron. For structural purposes the iron should be melted at least twice; that is, the castings should not be run direct from the blast furnace. Various mixtures of iron produce different results, and the remark made in the paper that it is not wise to restrict the ironmaster in his process of manufacturing wrought iron, also applies in this instance. It is better to specify that the iron shall stand certain tests, and allow him to make what mixtures and proceed in any way he may think proper, provided he make the desired quality of iron. One or two bars 3 feet 6 inches by 2 inches by 1 inch should be run each day with the castings, that is, they should form part of one of the actual castings and be detached after the casting is cool. With good ordinary iron such as should be used in construction, a bar of the above dimensions when placed on edge on 3-feet bearings,

should stand 28 cwt. to 30 cwt. applied at the centre, and give a deflection of at least $\frac{5}{16}$ of an inch before breaking. Large castings will not be equal in quality to the test bar cast with them on account of the thickness of the various portions. For this reason it is advisable in addition to breaking the test bar to apply a proof load to all large castings designed to resist heavy strains.

The cast iron of the sleepers for the Great Indian Peninsular Railway had to undergo tests very similar to this. In addition the sleepers had to stand a weight of $3\frac{3}{4}$ cwt. falling a height of 5 feet 6 inches, having previously been subjected to blows from this weight falling 2 feet, 2 feet 6 inches, 3 feet, &c., up to 5 feet 6 inches, being at the time of testing on sand not more than 24 inches deep. The average height required to break the sleepers was 7 feet 9 inches. The cast iron was also to stand a tensile strain of $11\frac{1}{2}$ tons per square inch, and the average was 13·07 tons.

This is undoubtedly a higher strain than most cast iron used in construction in this country will be found to stand; still by proper treatment, care, and an expenditure of money it may be much exceeded. The careful experiments carried out by the United States Government, and recorded by Major Wade, of their Ordnance Board, in a volume entitled "Reports of Experiments on the Strength and other Properties of Metal for Cannon, &c.," give the maximum tensile strain obtained with cannon iron at 20·5 tons per square inch; and the mean of samples cut from one hundred guns was 14·9 tons. These high results are obtained by remelting the iron, sometimes three or four times, and keeping it at each melting in a state of fusion for from one to four hours. As an instance of what may be effected in this way, samples cut from twenty-seven guns sustained a tensile strain of 15·75 tons per square inch; whilst the crude pig-iron from which these guns were cast only stood at 5·66 tons per square inch. More detailed information concerning these experiments may be found in a paper on "American Iron Bridges"

read by Mr. Zerah Colborn at the Institution of Civil Engineers, May 5, 1863. In the discussion which ensued on that paper, Mr. Bramwell gave some interesting particulars of similar experiments.

"He (Mr. Bramwell) exhibited two samples of Acadian cold blast iron, the produce of Nova Scotia, which had been broken in his presence by the proving machine at Woolwich Arsenal. Being No. 1 iron, a mixture of scrap was required before strength could be obtained. But as the experiments were made to test the quality of this individual iron, it would have rendered those experiments nugatory had scrap from any other source been mixed with the iron. The only way of proceeding that occurred to him was to melt some of the iron into pigs to make scrap for the second melting, reserving trial bars of the first melting. The order of the experiments was as follows:—The iron was put into an air furnace, and as soon as it was fused eight sample bars were cast. These bore an average tensile strain of 7½ tons per square inch of section. The iron was kept in fusion, and, two hours after, eight other bars were cast. These did not break until a strain of 8 tons 6 cwt. was attained, being nearly one ton more per square inch than the strain which broke the first lot of bars. After a further interval of one hour and three-quarters, eight other bars were cast, which broke with a strain of 10·8 tons; so that by keeping the metal in fusion for three hours and three-quarters, the tensile strength was increased from 7 tons 10 cwt. to 10·8 tons, or about 50 per cent. The iron was then poured out and pigs were cast from it. On the next occasion the furnace was charged with half of the fresh No. 1 iron, and half of the pig-iron from the prolonged fusion. The result was that the bars cast immediately upon melting required for their fracture a tensile strain of 11 tons.

Bars which were cast after four hours' fusion stood an average tensile strain of 18·5 tons, and the maximum of these samples stood as much as 19·6 tons.

CHAPTER X.

MR. GRAHAM SMITH ON "AMERICAN PRACTICE."

It is no uncommon circumstance to find American engineers speaking and writing of putting up spans of 150 feet to 250 feet in from two to four days. According to Mr. Lovett, chief engineer to the Ohio and Mississippi Railway, the last span of the Medora Bridge built for that company over White River, and measuring 147 feet 6 inches between centre and centre of end pins, was erected by four foremen and thirty-seven men in one day. In England a few weeks more or less for the erection of a bridge is not generally a matter of great moment, but for foreign work speed is often of paramount importance, as streams which can be walked across dry-shod one day are in the space of twenty-four hours converted into roaring torrents capable of washing away both the temporary staging and the girders in course of erection upon it. Another advàntage of speed in construction in foreign countries is the fact that the new road is often the only means of communication with its own more advanced portions, and until a certain bridge be constructed it may be difficult to convey materials for the advancement of distant works. There is a further consideration which may even make it desirable to introduce this class of bridge into England, namely, that nearly the whole of the work in the construction is performed by machines, and the erection may be carried on by unskilled labour directed by competent foremen. These are matters worthy of some attention in these days of strikes and inconsiderate and arbitrary restrictions imposed upon labour by various Unions. For instance, the day's work of a boilermaker

allowed by the Boilermakers' Club can be put in by twelve or one o'clock by a good average man working piece-work. This of course much enhances the value of riveted work, and it therefore behoves engineers to reduce as much as they consistently can the number of rivets in their bridge designs.

Touching upon the question of the comparative cost of the two systems, under normal conditions it may be roughly said that there is little or no economy in using pins in spans of less than 130 or 140 feet, as although the bridge may possibly be of less weight the price of the iron-work per ton is enhanced. It is often better when dealing with heavy moving loads accompanied by a greater or less amount of vibration to reduce the workmanship and increase the weight of the bridge in order to lessen the disparity in the weight of the structure and that of the moving load coming upon it. In such cases, as for instance a short span railway bridge subject to the traffic of heavy engines, riveted work may be employed with advantage. However, in bridges of, say, spans over 200 feet, in which the weight of the structure bears a large proportion to that of the moving load, it will no doubt be found advisable ultimately on the score of economy and policy to follow somewhat more in the track of our American brothers, more especially when a large number of similar spans are required.

The following tables, numbered I., II., and III., have been abstracted from a paper read at the fourth annual convention of the American Society of Civil Engineers, held at Chicago, June 5th and 6th, 1872, by Messrs. John Griffin and Thomas C. Clarke, of the Phœnixville Bridge Works, Philadelphia. These statistics of American bridge construction cannot fail to be of interest, representing as they do the practice of a large transatlantic bridge firm.

TABLE No. I.

Description.	No. of Driving Wheels.	No. of Truck Wheels.	Concentrated weight on drivers divided by length of driving wheel base.	Resulting weight per foot.	Total weight of engine and loaded tender divided by distance covered on track, including pilot.	Resulting weight per foot.
Actual Weights of American Engines and Rolling Stock.						
Class No. I. "Pushers."						
Reading Railway Tank, all	12	None.	102,000 / 19ft. 7in.	5,204	102,000 / 36ft. 0in.	2,833
Reading Railway Tank, with tender	10	"	82,200 / 15ft. 8in.	5,268	132,200 / 54ft. 1in.	2,448
Pennsylvania Railway, with tender	8	"	80,000 / 22ft. 0in.	3,636	140,000 / 54ft. 0in.	2,595
Baltimore and Ohio Railway, with tender	8	2	84,000 / 12ft. 6in.	6,720	128,000 / 53ft. 0in.	2,415
Fairlie, double-ender	12	None.	60,480 / 8ft. 0in.	7,560	120,900 / 52ft. 0in.	2,326
Class No. II. Heavy Coal and Freight.						
Chicago, Burlington, and Quincy, freight	6	4	72,000 / 12ft. 0in.	6,000	128,000 / 53ft. 6in.	2,392
Reading standard coal	6	4	53,000 / 9ft. 6in.	5,578	122,128 / 50ft. 3in.	2,430
Pennsylvania, standard freight	6	4	54,500 / 12ft. 5in.	4,360	129,900 / 54ft. 0in.	2,405
Delaware, Lackawanna, and Wilmington, standard freight	6	4	71,500 / 12ft. 5in.	5,948	138,900 / 54ft. 0in.	2,572
New York Central, special freight	6	2	65,000 / 15ft. 6in.	4,193	120,000 / 45ft. 0in.	2,666
Erie broad gauge, special freight	6	4	72,156 / 14ft. 6in.	4,976	137,444 / 54ft. 0in.	2,545

TABLE No. II.

Weight in lbs. for different classes of trains on various spans. Per foot run of span.							Dead weight of single line railway bridge, track rails, &c.
Length of span in feet.	All locomotives.	Coal train, cars (No. 20) drawn by two engines (No. 7).	Coal train, cars (No. 20) drawn by one engine (No. 7).	Freight train, cars (No. 19) drawn by two engines (No. 8).	Freight train, cars (No. 19) drawn by one engine (No. 8).	Passenger train, cars (No. 22) drawn by one engine (No. 16).	Per foot run.
Feet.							
Under 12	5,000	...	...	...	...	...	500
12 to 17	4,000	...	...	...	...	...	550
17 to 25	3,500	...	...	...	...	...	625
25 to 83	3,000	...	...	...	...	...	750
83 to 100	2,500	...	...	...	...	...	870
110	...	2,430	2,094	2,405	1,870	1,481	1,000
125	...	2,365	2,067	2,262	1,809	1,418	1,135
150	...	2,275	2,026	2,111	1,740	1,340	1,225
175	...	2,200	2,000	2,065	1,710	1,285	1,300
200	...	2,130	1,974	1,922	1,665	1,244	1,500
225	...	2,100	1,950	1,864	1,631	1,211	1,700
250	...	2,068	1,943	1,809	1,603	1,186	2,000
300	...	2,026	1,922	1,733	1,562	1,147	2,400
350	...	2,000	1,907	1,679	1,532	1,120	3,000
400	...	2,000	1,895	1,638	1,510	1,100	4,000

Particulars of iron bridges actually constructed by Messrs. Clarke, Reeve & Co. All these bridges have cross floor beams of iron. The longitudinal track stringers are of wood, unless otherwise mentioned. The general loads assumed for calculation are the weight of iron in column 9, plus the rolling load in column 7, and weight of track assumed at 400 lbs. per lineal foot. Iron in tension strained to 10,000 lbs. per square inch except in floor beam hangers, when it is strained to 7,500 lbs. per square inch. In compression "Phœnix" columns, upper chords of 12 to 15 diameters from 8 to 10,000 lbs. per square inch; 20 to 40 diameters 4 to 6,000 lbs. per square inch. These bridges are designed with leaning end posts unless otherwise described, and are all with two trusses.

TABLE No. III.

1	2	3	4	5	6	7	8	9	10
In what year built.	Where and for whom.	Deck or Through.	Number of Tracks.	Clear Length of Span.	Width between centres of Trusses.	Rolling Load lbs. per lin. foot. General.	Rolling Load lbs. per lin. foot. Floor and Pnl. Systm.	Weight of iron in lbs. per lin. ft. clear span	Remarks.
				ft. in.	ft.				
1875	Ottawa Rivar, Montreal and Ottawa Railway	D	1	50 0	10	4000	4000	594	Upright end posts
1875	San Paulo & Rio Janairo, Brazil	T	1	65 6	15	3000	4500	605	
1872	Hudson River, Albany N. Y. Central	T	2	70 0	29	6000	6000	1420	Iron track stringers & side walks
1870	Baileyville, Boston and N. Y. Air Lina	D	1	79 0	10	4000	4000	784	Upright end posts
1872	Littla Wabash, Ohio and Mississippi Railway	T	1	92 0	16	3000	3600	672	
1872	Greenbriar, Chesapeaka and Ohio Railway	D	1	100 0	10	2500	3600	637	Upright end posta
1875	New Orleans and Mobile Railway	T	1	104 0	15	2500	4000	622	
1875	Ticonic, Maine Csntral	T	1	111 0	16	2500	4000	655	
1872	Greenbriar, Chesapeaka and Ohio Railway	D	1	120 0	10	2500	3500	714	Upright end posts
1874	Lennoxvilla, Grand Trunk Railway	T	1	118 0	16	2500	4000	740	" "
1874	Biddaford, Eastern of Massachusetts	T	1	130 0	16	2500	4000	726	
1873	Little Androscoggin, Grand Trunk	D	1	135 0	11	2500	4000	770	
1875	Norwich Falls, Norwich and Worcester	T	1	145 0	16	3000	4000	910	Iron track stringera
1869	La Salle, Illinois Central	D	1	154 0	12	2500	3500	862	
1875	Lewiston, Maine Central	½D	1	161 0	16	2500	4000	954	Upright end posts
1872	Hudson River, Albany N. Y. Central	T	2	177 0	28	6000	6000	2585	Iron track stringers
1872	Medora, Ohio & Mississippi	T	1	160 0	16	2500	3600	810	
1874	Ticonic, Maine Central	T	1	170 0	16	2500	4000	856	
1872	Scottville, Ohio and Mississippi	T	1	172 0	16	2500	3600	873	
1875	Thamesvills, G. W. of Canada	T	2	180 0	29	4500	8000	1940	Iron track stringers
1874	Ristigoucha, Intercolonial of Canada	T	1	200 0	18	2800	3600	1140	" "
1874	Miramachi, Intercolonial of Canada	T	1	200 0	18	2800	3600	1105	" "
1874	Waterville, Maine Central	T	1	200 0	16	2500	4000	1076	
1875	Ottawa River, Montreal and Ottawa	T	1	200 0	16	2500	4000	1085	
1872	Naw River, Chesapeake and Ohio	T	1	250 0	16	2000	3500	1285	
1875	Susquehanna River, P. W. and B.	T	1	251 0	16	2240	3500	1421	Iron track stringers
1876	Susquehanna River, P. W. and B.	T	1	307 0	16	2240	3500	1895	" "
1870	Chester Creek, P. W. & B	T	2	150 0	26	2500	3500	1320	
1875	Ottawa River, Montreal and Ottawa	T	1	150 0	16	2500	4000	836	

The American system of sending out a specification of requirements and leaving each contractor to work out his own design, whilst having some disadvantages, undoubtedly tends to develop the talent and skill of engineers and contractors to a greater extent than our home system of allowing the engineer to make a design and invite tenders for its construction. The working of the former system entirely depends upon the plans being examined by a competent engineer and the board or directors accepting implicitly his decision without for one moment entertaining the question of accepting the lowest tender. English practice is too apt to seduce an engineer into erring in making the bridge strong enough irrespective of weight or cost. The following specification sent out in 1877, whilst containing much information, clearly indicates the manner of procedure across the Atlantic :—

GENERAL SPECIFICATIONS FOR RAILWAY AND HIGHWAY BRIDGE COMBINED, TO BE ERECTED FOR THE CHICAGO, MILWAUKEE, AND ST. PAUL RAILWAY COMPANY, OVER THE WISCONSIN RIVER AT KILBOURN CITY, WISCONSIN.

The entire superstructure will be of iron, including floor-beams and track-stringers. Cast iron will not be used, except for minor details. The railway company will furnish and place in the work the cross-ties, guard timbers, and rails for the railway, and the planking, floor-joist, and hand-rail for the highway, and furnish to the party erecting the structure timber and lumber necessary for the false work. Commencing near the east bank of the river and extending westerly, in the order named, the following spans will be required: One span of 53 feet, measured from the centre of its east-end pin to the centre of the east-end pin of the next span. This will be a deck bridge for the purpose of carrying the railway track over the approach of the highway. One span of 247 feet from centre to centre of end pins. One span, the centre of the west-end pin of which is 98 feet west of the centre of the west-end pin of the

247 feet span before mentioned. The 247 feet span will carry the railway track on deck, and on iron floor-beams suspended from the pins of the lower chord will rest the floor-joists and planking for the highway, and said joists and planking for highway will be continued on the same level and supported for a distance of 63 feet under the 98 feet span by iron floor-beams suspended from the lower pins of said span, or from an independent truss. No side-walk will be required, but the clear width between posts of the trusses of the 247 feet span, and also the suspension rods of the 98 feet span, if so constructed, must be at least 16 feet, and the clear height must be at least 14½ feet between any upper member and the top of suspended floor-beams for highway. The floor-beams for highway may be placed at such distance below railway track as will permit the beam to pass either under or over and close to the lower chord of the long span of the present structure, plan of which is herewith annexed. The clear width between the trusses of the 53 feet span shall be the same as that between the trusses of the 247 feet span. The gauge of the railway is 4 feet 8½ inches.

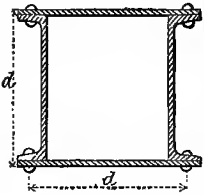
Quality of Iron.—The iron subject to tensile strain shall be tough, ductile, and of uniform quality, capable of sustaining not less than 50,000 lbs. per square inch of sectional area when tested in large or long lengths, to have an elastic limit of not less than 26,000 lbs. per square inch; the reduction of breaking area shall average 25 per cent., and the elongation of the bar before rupture to be at least 15 per cent., and when cold a round bar 1½ inch diameter must bend through 180° without sign of fracture. The iron subject to compressive strain must be tough, fibrous, uniform in quality, and have an elastic limit of not less than 25,000 lbs. per square inch. Cast iron (used only in minor details) shall be of the very best quality. The pins and all parts subject to shearing or bending strains shall be of the best quality of wrought iron.

Weight of Structure and Moving Load.—In determining the total weight of the structure for the purpose of calcu-

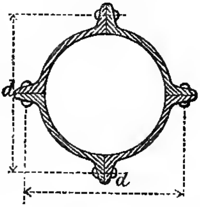
lating strains, there shall be added to the total weight of iron in the several spans 350 lbs. per foot of bridge for weight of rails, splices, spike, cross-ties and guard timbers above and exclusive of floor-beams and stringers for upper floor, and 550 lbs. per foot of bridge for weight of planking, floor-joists and hand-rail on the portion of bridge sustaining highway from lower chord pins. The first-mentioned span of 53 feet over approach of the highway will carry a single track railway above upper chord, and in calculating chord strains add to the dead weight 350 lbs. per foot for weight of track, &c., and use a uniform moving load of 4,000 lbs. per foot of bridge. For post and tie-strains, use the above dead weight, weight of track, &c., and the same moving load headed by a weight of 72,000 lbs. on a distance of 12 feet, and not produce strains in any of its members exceeding the maximum hereinafter mentioned. The 98 feet span will carry a railway track above upper chord, and in calculating chord strains, add to the dead weight the weight of track, &c., 350 lbs. per foot of bridge, and use a uniform moving load of 3,500 lbs. per foot, then add 8 per cent. to the strains thus derived for end panels, 6 per cent. for second panel, and use normal strains on and from the third panel from the ends on top chord and its corresponding lower panels, and for post and tie-strains use the above static weights and a uniform moving load of 3,500 lbs. per foot, headed by a load of 72,000 lbs. on 12 feet, and not produce strains in any of its members exceeding the maximum hereinafter mentioned. In case any portion of the highway roadway is suspended from the lower pins of this span, its dead weight, weight of floor and a uniform moving load of 50 lbs. per square foot of roadway surface must be considered in calculating strains. In case the 63 feet of roadway for highway purposes, under the 98 feet span, is supported by an independent truss, it shall be proportioned to sustain, besides its weight and 550 lbs. per foot of floor, a uniform moving load of 50 lbs. per square foot of roadway surface, in accordance with the require-

ments hereinafter mentioned. The 247 feet span will be proportioned as follows:—For chord strains use a uniform moving load of 3,100 lbs. per foot, in addition to the dead weight of structure and floors, then add 8 per cent. to the strains thus derived for end panels, 6 per cent. for second and third panels, and use normal strains on and from the fourth panel from the ends to top chord and its corresponding lower panels. For determining strains in posts and ties, add 700 lbs. per foot to the static or dead weight and

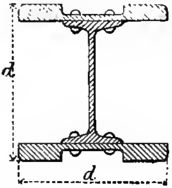
SQUARE COLUMN.



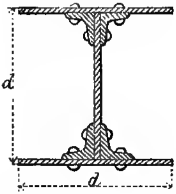
PHŒNIX COLUMN.



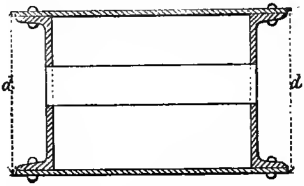
AMERICAN COLUMN.



COMMON COLUMN.



COMMON CHORD SECTION.



weight of floors, and for rolling load use 2,400 lbs. per foot, headed by a weight of 72,000 lbs. on 12 feet.

Tensile Strains.—The iron work to be so proportioned in each span that the maximum strains produced by the dead weight and floors, together with loads specified, shall in no instance cause a greater strain in tension than 10,000 lbs. per square inch upon the bottom chord and main ties, except the middle main ties, which as well as all counter ties and suspension rods, shall not be strained to exceed 8,000 lbs. per square inch. Floor-beam suspenders and all

other members liable to receive sudden shocks in tension, shall not be strained to exceed 4,000 lbs. per square inch.

Crippling Strains.—The ultimate crippling strength in lbs. per square inch of section of the several forms of posts, struts, and chords will be determined by the following formulæ, in which formulæ H equals the length between the end bearings in terms of the least diameter:—

	Square col.	Phœnix col.	American col.	Common col.
Flat ends	$\dfrac{38{,}500}{1+\frac{H^2}{5820}}$	$\dfrac{42{,}500}{1+\frac{H^2}{4500}}$	$\dfrac{36{,}500}{1+\frac{H}{3750}}$	$\dfrac{36{,}500}{1+\frac{H^2}{2700}}$
One pin end . . .	$\dfrac{38{,}500}{1+\frac{H^2}{3000}}$	$\dfrac{40{,}000}{1+\frac{H^2}{2250}}$	$\dfrac{36{,}500}{1+\frac{H^2}{2250}}$	$\dfrac{36{,}500}{1+\frac{H^2}{1500}}$
Two pin ends . .	$\dfrac{37{,}800}{1+\frac{H^2}{1900}}$	$\dfrac{36{,}600}{1+\frac{H^2}{1500}}$	$\dfrac{36{,}500}{1+\frac{H^2}{1750}}$	$\dfrac{36{,}500}{1+\frac{H^2}{1200}}$

The pin being so placed that the moment of inertia is, as near as practicable, equal on both sides of same. Use formulæ for common column. The maximum strain permitted in any compressive member will be the quotient resulting from dividing the ultimate strength, as determined by the above formulæ, by a coefficient of safety, equal to $4 + \frac{6H.}{100}$ "H," as before, being the measure of length in terms of least diameter.

Pins.—The shearing strain on any pin must not exceed 7,000 lbs. per square inch of its sectional area. The strain on extreme fibres caused by bending must not exceed 15,000 lbs. per square inch, and in determining this bending strain, the leverage distance shall be considered as from centre of eyebar to centre of bearing or of opposite eyebar. No pin shall have a less diameter than two-thirds of the widest eyebar coming upon it. The bearing surface of any pin on chord, tie, or post shall not be exposed to a greater strain than 10,000 lbs. mean pressure on the semi-extrados. Pins

must be turned to size and straight, no error of more than $\frac{1}{50}$ of an inch in diameter being allowed.

Eyebars.—Pinholes in eyebars shall be bored to exact sizes and distances, and to a true perpendicular to the line of strain. No error in length of bar or diameter of pinhole exceeding $\frac{1}{64}$ of an inch will be allowed. The section of metal in the eye opposite the centre of the pinhole and perpendicular to the line of strain, shall be proportioned according to the following table, the diameter of the bar being the unit:—

HYDRAULIC FORGED EYES ON WELDLESS BARS.			HAMMERED EYES WELDED TO BARS.		
Pin.	Bar.	Eye-section.	Pin.	Bar.	Eye-section.
1·00	1·0	1·50	0·75	1·0	1·33
1·25	1·0	1·60	1·00	1·0	1·50
1·33	1·0	1·70	1·25	1·0	1·50
1·50	1·0	1·85	1·50	1.0	1·67
1·75	1·0	2.00	1·76	1·0	1·67
2·00	1·0	2·20	2·00	1·0	1·75

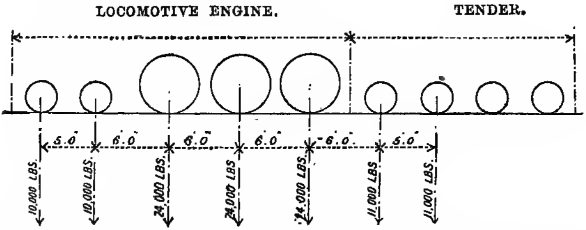
No eye on a weldless bar shall have a metal section less than $1\frac{1}{2}$ times the area of bar, and for hammered eyes the least eye-section shall be $1\frac{1}{3}$ the section of the bar. A drawing of the standard shape of the eye proposed to be used must be filed with each proposal.

Riveted Work.—In riveted work all joints shall be square and truly dressed. Rivet holes shall be accurately spaced, and the rivets must be of the best of quality of iron for the purpose, and completely fill the holes. In all posts and chords the connecting rivets within two diameters of the ends shall be equal to the sectional area of the joined pieces, and in posts and elsewhere in all riveted work the rivets shall not be spaced to exceed sixteen (16) times the thickness of the thinnest plate joined by them, and the distance between rivet supports across the plate shall not exceed thirty (30) times the thickness of the plate, and no closed section shall have members of less thickness than $\frac{5}{16}$ of an inch. The parts composing the posts and struts must be of entire lengths without splicing between end

bearings. All workmanship must be first-class; abutting joints must be truly planed or dressed so as to secure a perfect bearing, and the pinholes in chords and posts shall be bored as truly as is specified for the eyebars. All closed work, such as posts, struts, chords, &c., must have two (2) coats of approved metallic paint and boiled oil on the enclosed surface, and one coat on the exterior surface, before leaving the shop. All turned and faced parts to receive a coat of tallow mixed with white lead before shipment.

Wind Strains shall be calculated at 30 lbs. per square foot on twice the surface of the truss, plus ten (10) square feet per foot of bridge for car-service, and the resulting strains therefrom shall be resisted by lateral and vertical rods proportioned to 15,000 lbs. per square inch in tension, and lateral struts proportioned to a factor of safety of four (4). Shearing and bending strains at the lateral connections shall be calculated with the same precision as the main strains, and shall be resisted by members proportioned so that the maximum shearing strain shall not exceed 10,000 lbs. per square inch, and the maximum flexture or bending strain shall not exceed 22,500 lbs. per square inch.

Floor Beams and Track-stringers.—The railway floor-beams shall be proportioned for the concentration of weight occasioned by the following engine resting with middle driver over the floor-beam in question:—



To this live load there shall be added 25 per cent. for momentum and the dead weight of the floor and stringers,

and the resulting strains therefrom shall not exceed 8,000 lbs. per square inch in compression or 10,000 lbs. per square inch in tension. The stringers immediately under the rails shall be proportioned to carry the above described engine weight plus 30 per cent. for momentum and their proper proportion of floor. If the floor-beams and stringers are of built sections, the rivets must be so spaced that between the points of application of the load and the points of support there are rivets enough to transmit the flange strains to the web and from the web to the flange without exceeding a shearing strain of 7,500 lbs. per square inch upon the rivets, or of 10,000 lbs. per square inch of mean pressure on the semi-intrados of the rivet-holes. There will be an exterior pair of iron stringers placed 3 feet outside of the main stringers. These outer stringers will be proportioned to one-half the strength of the track-stringers under the rails.

Highway Floor-beams.—The highway floor-beams shall be proportioned to carry the floor weight of 550 lbs. (per lineal foot of bridge) and a live load of 700 lbs. per lineal foot of bridge. They shall also be proportioned to carry a concentrated load of 12,000 lbs. on one pair of wheels of six (6) feet gauge (in addition to the dead load), and the mode of computation which gives the greatest section shall be adopted—the specification as to strains and rivet sections prescribed for the railway floor-beams shall be adhered to for the highway beams.

Bed Plates and End Supports.—Bed plates resting on masonry shall be so proportioned that the pressure on the masonry shall not exceed 35,000 lbs. per square foot for the main span, and 25,000 lbs. per square foot for the smaller spans.

Friction Rollers.—The friction rollers, where used under the ends of a span, shall be so proportioned that the strains per lineal inch shall not exceed those determined by the following formula:

$\sqrt{540{,}000 \times d} =$ lbs. per lineal inch in which "d"=

diameter of roller in inches. The east end of the 247 feet span and the west end of the 53 feet span will be supported from the underside of the upper chord on proper iron plates or saddles resting directly on the masonry of pier, the said pier having an archway through same for the passage of highway. This pier will be constructed by the railway company, of the proper height and form to suit the requirements of the bridge. The west end of the 247 feet span and the east end of the 98 feet span will be supported from the underside of upper chords on iron supports extending to the masonry of the present pier, on a level with the bottom of highway floor-joists. This support will be constructed of wrought iron, strongly braced to resist lateral movement, and shall be so proportioned that the iron in it shall not be strained over 60 per cent. of the maximum strains permitted in forms of similar kind before mentioned. The space in the clear width and height of this structure, for passage of highway, may be not less than 13 feet. The plan of the top of the present pier, on which the proposed iron support is to be placed, is herewith furnished, and shows what portion of the pier can be occupied by the support without interfering with the present structure. The length of the spans mentioned contemplate placing the west-end pin of the 247 feet span over the exact centre of the masonry pier now built. If for the purpose of securing a more proper bearing in connection with the 98 feet span resting on the same pier, it is desirable to reduce the length of the 247 feet span a trifle, such reduction may be made, and in this case the 98 feet span will be correspondingly increased in length.

Camber.—The several spans shall have a permanent camber of $\frac{1}{1200}$th of their length. To more thoroughly understand the position of the several spans mentioned in their relation to the existing structure, see plan of same herewith furnished. The proposed bridge will be so located that its north truss will be north of and as close as convenient to the north chord of the present structure, and the south truss will be placed at its proper distance between

the chords of the existing structure, and the centre line of the railway will be changed to suit the new structure. For convenience in raising, the grade of the track can be temporarily or permanently raised or lowered 6 inches. The present long span is strengthened by two (2) supports built up from the river bed, and is strong enough to carry the additional weight of the new structure and necessary false works. Whatever false work may be necessary, and whatever changes may be required in re-arranging the floor-beams, lateral and sway bracing, &c., or any portion of the old structure, to permit the raising of the new, shall be done under the approval of the railway company's engineer, by and at the expense of the contractor, the timber and lumber necessary being furnished by the railway company, and the entire work shall be done without interfering with the passage of regular trains over the same. The railway company will remove the old structure on completion of the new. Any work or part necessary to complete the entire structure in all respects in a first-class manner, and which is not definitely specified herein, shall be supplied without extra charge by the contractor, and to the entire satisfaction of the engineer of said railway company.

Tests.—A skilled inspector will be retained by the railway company, who will examine and test the iron at the rolling mill before it leaves for the shop, and who will have the shop work under his constant supervision, with full power of rejection whenever the specifications are not complied with. The engineer of the railway company shall have the privilege of selecting, at any time before the erection of the bridge, any of the manufactured iron members and submit the same to such tests as he may deem proper, and should any of the members thus tested fail to be of the standard demanded, this will be considered sufficient evidence that the iron for the bridge does not comply with the specification, and will cause its rejection. Reasonable compensation will be allowed for all material of good quality destroyed in making such tests. All bars subject to tensile strain shall be tested by the contractor,

under the direction of the engineer of the railway company to 18,000 lbs. per square inch of sectional area. On completion of the entire structure, and after the present structure is removed, the bridge, after being in current use for one day, will be tested with a train loaded approximately to the maximum specified, and after remaining on the several spans for thirty minutes and then removed, no permanent set should take place. For the purpose of determining the stiffness and stability of the entire structure longitudinally and laterally, it will be subjected to the following test, viz. :—A train consisting of one engine, tender, one mail, one express, one baggage, three (3) passenger cars, and one sleeping coach, or their equivalent, with air-brake equipment, will approach from the west and run on to the bridge at the rate of twenty-five miles per hour approximately, and when the engine is over the centre of the 247 feet span the engine will be reversed and the air-brakes applied with sufficient force to slip the truck wheels, and no permanent change shall take place in the whole or any part of the structure.

All engineers are now aware that something more is necessary for constructive purposes than iron which will stand a high tensile strain. It has already been pointed out in the paper that a bridge constructed with hard brittle iron will, in all probability, stand the dead-load test to all appearances with less signs of distress than a similar structure in the construction of which good tough iron has alone been employed. This is simply because the iron does not stretch, and, assuming the workmanship equally good in both cases, the bridge built with hard brittle iron will deflect less under the test load. It is advisable therefore when testing iron to enforce the specified elongation or contraction of area even with more firmness than the ultimate breaking strain. This view is to some extent endorsed by the following extracts from the report of Mr. Lavington E. Fletcher, chief engineer of the Manchester Steam Users'

Association, on the Blackburn boiler explosion which took place in 1874 :—

"Tensile strength, however, is not the only quality required in boiler plates; ductility is also necessary. This is too often lost sight of. A plate with a moderate tensile power, if ductile, is better for boiler purposes than with a high tensile strain, if short and brittle. To ascertain the ductility of the plates under consideration reference may be made to the reduction in area at the point of fracture given in the first of the preceding tables. It will be seen that this reduction in area varies considerably in different experiments. In the case of the test plates cut from the top of No. 2 boiler, it is as low as 5·97, while the mean of the tests cut from the top of that boiler is 7·29. This does not indicate a high ductile power. The same inequality will be seen in the rate of elongation, which in one case was 1·97 per cent., in another 7·60 per cent.

"The result of the investigation of the quality of the plates is, that though adequate in tensile power, they had not, at all events some of them had not, that amount of ductility which it is desirable they should have seeing they were to be employed in the construction of a boiler to be worked at so high a pressure as 80 lbs. on the square inch. I do not consider, however, that the want of ductility was by itself the cause of the explosion."

The working strain to be put upon iron ought to be governed by the specified quality and tests, as well as by considerations affecting the purposes to which it is to be applied. When the moving load is relatively large to the dead weight of the structure, it will generally be found more judicious to employ an ordinary quality of iron with a small working strain, than to employ an exceptionally good material capable of sustaining a high working strain. Where good ordinary iron has been tested and found to be of a reliable character, it might be loaded with a dead weight to such an extent as to put a strain of six or even seven tons per square inch upon it without danger; but in

a small railway bridge of, say, 20 feet span it is not safe to impose a greater strain than four or four and a half tons per square inch upon the iron, on account of the varying and almost indeterminable effect of the rolling load. If a higher working strain is taken the rolling loads may cause the limit of elasticity of the iron to be exceeded, and however rarely this happens the structure must ultimately wear out. If an adequate rolling load be assumed, and a low strain be put upon the iron, good designing ought to render the wearing out of an iron structure in this way almost impossible, more especially as it would appear that the practical limit to the weight of locomotives has now been reached.

If girders are of the lattice type every care should be taken to provide for these heavy rolling loads by introducing counter-bracing, or by so designing the diagonals that they may be capable of sustaining the maximum strains both of tension and compression. In modern bridges designed by our first engineers it is no unusual circumstance to find the strain allowed in the centre diagonals to be about two tons per square inch.

Sir William Fairbairn, at the request of the Board of Trade, carried out many experiments with the view of determining the effect of rolling loads. These will be found in his Third Series of "Useful Information for Engineers," and from these experiments the following particulars have been extracted, as they bear closely on the questions under consideration:—

A wrought iron riveted plate beam 20 feet clear span, 16 inches deep, nett effective area of bottom flange 1·775 square inches, gross area of top flange 4·3 square inches, web $\frac{1}{8}$ of an inch thick, weight of girder 7 cwt. 3 qrs., calculated breaking weight in the centre 12 tons.

By suitable mechanism put in motion by a water wheel, loads were put upon and taken off this girder at the rate of about eight applications per minute without intermission either day or night.

With a load of 6,643 lbs., or about one-fourth of the ultimate breaking load, the calculated strain in the bottom flange was 6·25 tons per square inch of effective section, the deflection at the centre was 0·17 inches, which was not increased by 596,790 applications of the above load. At this point the load was increased to two-sevenths of the ultimate breaking load, so inducing a calculated strain of 7·39 tons per square inch of effective area in the bottom flange. The deflection was augmented to 0·22 inches, and after 403,210 applications, it was ascertained to be only 0·23 inches. As the beam had thus sustaiued one million changes of load without any apparent injury, the load was further increased to 10,486 lbs., or two-fifths of the breaking weight. After 5,175 applications of this load the beam broke by tension a short distance from the middle, the calculated strain on the iron at that point being 9·88 tons per square inch of effective area.

The beam after being repaired was again subjected to 3,150,000 applications of a load equal to one-fourth of its breaking weight. This load producing no effect whatever, it was increased to one-third of the breaking weight with which the beam failed by tension after 313,000 applications, the strain in the bottom flange being 8·45 tons per square inch of effective area.

From these results it would appear that the limit of elasticity of the iron of which this beam was constructed was about 8 tons. It required 313,000 applications of the load inducing a strain of 8·45 tons per square inch in the bottom flange to produce fracture, whilst with 403,210 applications of the load inducing a strain of 7·39 tons per square inch the girder sustained no injury whatever. It is well to notice that the beam was uninjured by nearly 4,000,000 applications of a load producing a strain of 6·25 tons per square inch in the bottom flange, whilst it required only 5,175 applications of the load inducing a strain of 9·88 tons per square inch to produce fracture. There is every reason to infer from these result that the beam

would have sustained an infinite number of applications of a load equivalent to one-fourth, or even approaching two-sevenths of its breaking weight.

The importance of these and analogous investigations are at once appreciated on an engineer being called upon to design new railway bridges, or to look after those already erected.

Mr. Benjamin Baker has conclusively proved, in his admirable little work on "Long Span Railway Bridges," that there are many circumstances, such as badly maintained permanent way, inclined cylinders, and unbalanced portions of the mechanism of locomotives, together with great weight and length of engines combined with short wheel base, which will at times render the effective load on one axle equivalent to 30 tons. This, taken with the deductions from Sir William Fairbairn's experiments, will almost render it necessary for an engineer to limit the life of railway bridge platforms constructed as of old with closely spaced shallow cross girders.

When a platform is first constructed every care is taken to have no two joints in longitudinal timbers on the same cross girder; unfortunately timber is a perishable material and railway work renewals are often left to the charge of navvies. They not being well versed in the art of bridge building sometimes make the longitudinal timbers to joint on the same cross girder, and in the case of a double line of way three out of the four may be found to do so. This is not all the navvies' fault; common sense, of which he has not a little, directs otherwise; but in order that traffic may not be interrupted, a short portion is commenced and finished at a time.

Assume a single line bridge with cross girders 3 feet 6 inches apart, originally designed to sustain 15 tons to each axle with a maximum strain on the iron of the bridge not exceeding 5 tons to the inch. Reasons have already been given why this load will at times be augmented to 30 tons, and the longitudinal timbers be decayed and jointed on the

same cross girder. It will not require more than 5 tons to each axle to produce the amount of deflection in the rails and timbers to correspond with that of the cross girder occasioned by the 25 remaining tons. But since a load of 15 tons to an axle induces a strain of 5 tons per square inch on the iron of the girders that produced by 25 tons will $= \frac{25 \times 5}{15} = 8{\cdot}33$ tons. Fairbairn's beam failed with 313,000 applications of a load producing practically this strain per square inch; therefore if the bridge be situate on a portion of a line subject to a traffic of sixty trains a day, going full speed, and the excessive load of 30 tons to one axle be only due once to each train, it will require but fourteen years to cause the destruction of the platform. The load of 30 tons may be due to either the leading, driving, or trailing axles. The effect of the engine only need be considered, as the strains induced by the remaining rolling stock will be well within the limit of elasticity of the iron. The economy is thus made evident of keeping qualified men to look after a railway, who will see that everything is kept in a good working condition. Bad permanent way not only ruins the rolling stock and passengers' constitutions, but it greatly adds to the wearing out of the bridge platforms. With shallow cross girders oscillations are set up by heavy continuous traffic, which will soon shake loose rivets and bolts, and perhaps the connections with the main girders.

It may be remarked by some who have never noticed a worn-out bridge platform, that calculations of the foregoing nature show ignorance of actual work, and that assumptions such as that each train may produce one excessive strain on a cross girder, may do very well for theory, but prove fallacious when subjected to the crucial test of practice. This may be so, for possibly the excessive load may occur more than once to each train, the constructive weakness referred to doing much to cause this effect. The author considers that the foregoing deductions point out

some pitfalls to be avoided, and clearly show the effect of moving loads on girders and analogous constructions. Here is an actual example recorded in the before-mentioned "Long Span Railway Bridges," a book which all connected with railway work should read. The platform of the railway bridge over the Regent's Canal was constructed, owing to local circumstances, with cross girders only 8 inches deep and 14 feet 6 inches span. With a view of compensating as much as possible for want of depth, longitudinal stiffening girders 18 inches deep were placed at a distance of 2 feet 3 inches from the outer edge of each rail; each cross girder was also well secured by tee irons and gusset plates to the main girders. This bridge, notwithstanding that with 15 tons to one axle it was so designed that the iron should not be strained to more than 4 tons per square inch, completely gave way in four years. Mr. Baker attributes the failure to the employment of a 45-ton engine to work the traffic, the wheel base of which was 14 feet; the ends consequently overhung very much, which would greatly assist in producing oscillation and other undesirable consequences.

In good modern practice closely spaced shallow girders are only used where absolutely unavoidable. It is more often found that the distance between cross girders is 7, 12, or even 20 feet. The latter is an extreme not recommended on the score of economy; for even supposing a saving in the weight of platform, which is not likely to be effected, it would probably not be economical to space the triangulations of the web of the main girders at 20 feet centres, as the compression members would so be rendered unduly heavy. By introducing another system of zig-zag, the distance between the cross girders is reduced, and no doubt a saving effected in the total weight of the structure.

These and other kindred questions admitting of no general solution are entirely dependent on the ability of the designer. In warren, trellis, and even plate girder bridges, the spacing of the cross girders is in most cases,

to a great extent, fixed by considerations affecting the main girders.

So far as approximate weights for taking out strains and parliamentary estimates are concerned, the weight of iron in a properly designed double-line bridge platform with two main girders may be taken at 9 cwt. per foot run, within the limits of 8 feet 6 inches and 20 feet spacing of cross girders; that is assuming the iron not to be strained with the heaviest loads to more than 4 tons in the former and $4\frac{1}{4}$ tons per inch in the latter instance. On the completion of the design there will of course be no difficulty in ascertaining the accurate quantities.

Mr. William Anderson was among the first to appreciate and point out the great economy to be derived from properly spacing cross girders. This is exhibited, apart from any consideration affecting the other portions of the bridge, in the following table of estimates prepared by him, and kept on record in the "Transactions of the Institution of Civil Engineers of Ireland," vol. viii., 1866.

	Span.	Total Load on Girders.	Nett Area of bottom Flange.	Weight of Girders.	Weight per Foot Run of Bridge.
SINGLE LINE.	ft.	tons.	sq. in.	lbs.	lbs.
Cross girders 3 ft. apart	14	17·26	6·30	1206	402
Cross girders 12 ft. apart	14	29·35	10·93	1700	268·2
Longitudinal rail girders	12	19·54	10·80	1518	
DOUBLE LINE.					
Cross girders 3 ft. apart	$25\frac{1}{2}$	35·00	11·40	3654	1218
Cross girders 12 ft. apart	$25\frac{1}{2}$	58·64	19·20	4704	645
Longitudinal rail girders	12	38·64	21·60	3026	

It may be remarked that the weight per foot run of platform girders given by the author is considerably in excess of that contained in the table. In the former instance the strain of the iron is taken low, and the damaging action of a 45-ton engine is provided for, whilst in the latter the data assumed are—maximum weight of engine 34 tons, maximum load on a pair of driving wheels 16 tons, wheel

base 12 feet, depth of cross girders $\frac{1}{12}$th of clear span. The ever increasing, complications in running powers, taken in conjunction with the various types of engines used on railways, will necessitate the weight given by the author on almost any railway to be constructed in this country; still the relative comparisons exhibited in Mr. Anderson's table hold good, and are of great value. It must not be assumed that in spacing cross girders within the limits of 3 feet and 12 feet, that the weight of the platform will vary and be proportional to their distance apart.

Extract from Discussion on Mr. Graham Smith's Paper read before the Liverpool Engineering Society, June 20th, 1877.

ON CROSS-PILING.

Mr. Birch said with reference to the author's remarks on cross-piled plates, that his experience had been that beyond certain limits cross-piling was ineffectual to produce tensile strength crossways equal to that in the direction in which the iron was rolled. In fact, in plates of ordinary sizes the strength, as a rule, would always be three or four tons more lengthways of the plate. In support of his assertion, Mr. Birch read the following notes on the subject which he had had from one of the largest plate manufacturers in this country, whose works, situate in the Cleveland district, are employed in nothing else but the manufacture of ship, bridge, girder, and boiler plates:—

"We do not ourselves think there is so much in cross-piling as is generally believed. We find that in rectangular plates of ordinary sizes the strength in the direction of the rolling is to that in the opposite direction as twenty-two is to eighteen. In long narrow strips you may increase the first, but always at the expense of the second. In smaller square plates specially rolled you may make it almost equal in both directions. We do not think that a plate 12 feet by 4 feet 6 inches by $\frac{3}{4}$ inch can under any circumstances be made to stand an equal strain both ways,

for it would of necessity have to be rolled out more in one direction than the other; and cross-piling does not by any means compensate for the effect of finally rolling in an opposite direction. The percentage of elongation follows very much the final tensile strength—that is to say, it increases or diminishes with the tensile strain endured. Some makers—notably Low Moor and Farnley—are putting down rolls of great diameter and length—say, 12 feet long by 2 feet 8 inches diameter. They make a speciality of large circular plates to flange all round, and with two flanged holes in them for marine boilers. Their object is to obtain equability of tensure for flanging purposes, by an equal amount of rolling in both directions, and no doubt they obtain it in this way. The cost, however, must be greatly enhanced, for apart from the question of the high class material they use, such machinery is of a most expensive kind in original cost and in keeping in motion. As plates of this description are a very small proportion of the total used for all purposes, it is clear that the size and class of machinery ought to be determined by the bulk of orders, and not by the requirements of exceptional plates. The term cross-piling seems to have come originally from Staffordshire, and is not used at all by manufacturers of plates. We constantly hear of it, however, from merchants and consumers who imagine there is something in it, but don't know what. As far as we can gather, 'cross-piling' in Staffordshire means making the pile from which the plate is to be rolled with one slab top and bottom lengthways of the pile, and the intermediate space filled up with puddled bars placed crosswise. Our experience is that plates so made are very inferior to plates made as we are in the habit of doing them, viz. with one or more slabs lengthways of the pile top and bottom and the intervening space filled up with plate scrap. This is for ordinary quality. For higher qualities we have several methods of improving the iron, though not without increased cost. It is quite probable that plates cross-piled as we have described them

may be better than plates made of new puddled bars all arranged the long way of the pile, but we never make them the one way or the other. As before explained, more depends on the direction of the rolling afterwards than on any particular arrangement of piling. You may make up your mind that it is not wise for merchants or consumers to specify anything about piling, or any detail of the manufacture of iron. Their best policy is to specify that the iron should be capable of bearing such and such tests. They then throw the responsibility on the manufacturer, whereas, in the other way, they take it themselves, for they cannot blame him if he follows their instructions, even though a failure be the result."

Punching Iron.

The following experiments carried out by Mr. Cochrane (*vide* Minutes of the Institution, vol. xxx.) tend to show that the punch does not damage iron to the extent supposed by some engineers. A bar of Low Moor, 2 inches by ½ inch, with a drilled hole ⅞ inch diameter put through it, sustained 235 cwt., and with a punched hole 226 cwt. With bars of hard crystalline iron of the same dimensions that with the drilled hole sustained 250 cwt. and the punched hole 244 cwt. With bars each with three holes, one drilled, one punched, and one punched ¾ inch and drilled to ⅞ inch diameter, in all cases they broke through the punched hole. This would be inferred from the foregoing experiments, still the results are well within the limits of variation in the breaking weights of our best irons.

APPENDIX.

SPECIFICATION

FOR THE ERECTION AND COMPLETION OF A WROUGHT-IRON LATTICE GIRDER BRIDGE OVER THE RIVER , AT , 140 FEET CLEAR SPAN, AND 54 FEET WIDE BETWEEN MAIN GIRDERS.

1. **Interpretation.**—In this specification the words "The Corporation" shall be understood to mean the mayor, aldermen, and burgesses of the borough of ; the words "Town Clerk" shall mean the town clerk of for the time being; the word "Contractor" shall mean any person or persons who may jointly or severally enter into any contract for the execution of the works herein specified, or any of them, and shall include his or their heirs, executors, and administrators; and the word "Engineer" shall mean the borough engineer of , or other the engineer or surveyor for the time being duly authorised by the corporation to act as engineer or surveyor in the construction of the works herein specified, or his representative.

2. **Extent of Contract.**—The contract comprises the manufacture, erection, painting, and completion of the whole of the wrought and cast iron work for the bridge, including all labour and materials necessary for fitting and fixing the same in position upon the abutments now in course of construction at , and maintaining the same in perfect order and condition for three months after its completion and opening for public traffic; and also the providing, erecting, and afterwards removing of all temporary materials, including all staging, piling, scaffolding, tools, tackle, and machinery necessary for erecting, fitting, fixing, and finishing off the work in the most

complete and perfect manner, to the satisfaction of the Engineer.

DRAWINGS.

No. 1. General elevation of bridge
,, 2. Plan showing girders.
,, 3. Elevation of main girder.
,, 4. Details of main girder.
,, 5. Section of bridge showing details of cross girders.
,, 6. Details of short cross girders.
,, 7. Details of cornice and diagonal bracing.

3. **Main Girders.**—There are two wrought iron main girders of the tubular lattice form, 154 feet $10\frac{1}{2}$ inches over all, 14 feet $8\frac{3}{4}$ inches total depth, and the flanges of trough section 3 feet 6 inches wide, the web of the trough being 2 feet deep. The girder to be built with $3\frac{1}{2}$ inches camber. The main girder must be fixed on the abutments at such a height that the underside of the bearing plates shall be 95·30 above ordnance datum, and the contractor must satisfy himself that the masonry is at the proper height for fixing the girders.

4. **Cross Girders.**—The cross girders are twenty-seven in number, 6 feet apart from centre to centre; nineteen of them are 54 feet span, 4 feet deep at centre, and 3 feet deep at ends, curved in both flanges, which are 18 inches wide. They rest upon the bottom flange of the main girders, and are connected thereto by a continuation of the cross girders to the outside member of the web, to which it is riveted. The remainder, four at each end of the bridge, are of various lengths, as shown on the drawings, and have one end attached to the main girder, and the other resting upon the abutment. The two shorter girders out of the four will be 3 feet 6 inches deep, the top flange only being curved.

5. **Setting Out.**—The main girders and cross girders must be carefully and accurately set out full size at the contractor's works in order to get the correct lengths for tho various parts, and to ensure a perfect fit and accurate butt joints throughout the whole work.

The floor-plates are 3 feet wide and $\frac{3}{8}$ inch thick, supported by T irons 5 inches by 3 inches by $\frac{1}{2}$ inch, running parallel to the main girders and riveted to the cross girders.

The plates to have a camber of 3 inches between the T irons to which they are riveted.

6. **Wrought Iron.**—The whole of the plates, T angle, and other rolled iron, are to be of the best quality, by a maker to be approved of by the engineer, sound, tough, free from all cracks, flaws, indentations, and other defects, cinders, and other impurities, carefully straightened, flattened, and, where necessary, curved to the required shape before being drilled, so that the surfaces shall be in contact. They shall gauge everywhere the full thickness and dimensions figured or shown on the drawings, be truly planed at the ends to make accurate butt joints, and shall in all respects be well and truly fitted and put together with all necessary packing pieces, whether shown on the drawings or not.

The whole of the rolled iron above mentioned to be capable of being bent to a right angle when cold without fracture, and of bearing a tensile strain of ten tons per square inch of section without permanent set, and at least twenty-one tons per square inch before fracture.

7. **Diagonals.**—The diagonal bars for the main girders must be made from the best quality of double hammered scrap iron; they must all be perfectly flat, straight, sound, and free from cracks or flaws of every description, solid at the edges and ends, forged or rolled in one piece, as no welding on the ends will be allowed; they must everywhere gauge the full width and thickness shown or figured on the drawings, and be set out with especial care to the exact length required. They must be capable of being bent when cold to a right angle, and bearing a tensile strain of twelve tons per square inch without permanent set, and at least twenty-two tons per square inch before fracture.

8. **Drilling.**—All rivet holes in the main girders, and the ends of the cross girders where they are attached to the main girders, to be carefully and accurately drilled to templates, through the whole thickness of plates required to be riveted together at one operation, the plates being built up in the position they will occupy in the girder for this purpose, so that all the holes which have to be passed through by any rivet correspond with each other, and the plates can be riveted up without "drifting" or "riming"

out the holes. After the plates are drilled, the sharp burr and arris left by the drill must be taken off to prevent shearing of the rivets. The rivet holes in the cross girders, except those above mentioned, are to be carefully and accurately punched to templates.

9. **Rivets.**—The rivets must be made from the very best quality of rivet iron, capable of bearing a tensile strain of eighteen tons to the circular inch of section before fracture. The rivets for the main girders to be $\frac{7}{8}$ inch diameter and 4 inches pitch, except for the lateral bracing of the verticals and diagonals which have $\frac{3}{4}$-inch rivets. The rivets to be cup-headed, the total height of the finished head of a $\frac{7}{8}$-inch rivet to be not less than $\frac{11}{16}$ inch; no "drifting" will be allowed. The rivets for the cross girders are to be $\frac{3}{4}$ inch diameter and 4-inch pitch. The rivets at the bearing-plates of the main girders, and in all cases where necessary, must be counter-sunk, whether they are so shown on the drawings or not. No rivets to be hammered when cold.

10. **Bolts and Nuts.**—All bolts are to be made of iron of similar quality to the rivets, and capable of bearing the same test. They must be made to the full sizes shown on the drawings, the heads to be forged in one with the bolt out of the solid rod, and not by "welding" or "dabbling" on a separate piece. The heads of the 1-inch bolts must be at least $\frac{7}{8}$ inch deep, and the nuts 1 inch deep. The screws for both bolts and nuts to have Whitworth's standard threads, well and cleanly cut, and to hold full for the entire length of the screw. The nuts to be neatly formed and fit the bolts tightly.

11. **Cast-iron Bed Plates.**—The cast iron is to be of the best and toughest quality, and the castings generally must be perfectly sound, clean, and free from air or sand holes, and of the exact dimensions shown on the drawings; the surfaces of the expansion plates, or any other parts which the engineer may consider necessary, must be planed or faced. They must be cast to the proper angle for fitting the face of the abutment.

12. **Cornices and Panels.**—The cornices and panels for the Salford Arms to be clean sound castings, sharp in the mouldings and arrises, straight, true, and free from warp

or bend, and properly fitted and fixed to the main girders, as shown on the drawings, including all necessary drilling and tapping, counter-sunk screws, bolts, and nuts; all joints to be fitted up flush.

13. **Lamps.**—Four three-light lamps, of a pattern similar to that shown upon the elevation, to be approved by the engineer. The lights to have copper frames, each weighing lb., glazed with 26-oz. glass, hinged doors at bottom, one half glazed and the other half perforated copper.

14. **Inspection.**—The engineer shall have the right of inspecting any portion of the ironwork, either at the works during the process of manufacture or after delivery; and either himself or his representative shall have free access to the works at all times, full power and facilities to apply at the contractor's own expense such tests as he may from time to time deem expedient, and to reject either before or after delivery any of the work which he may consider defective, incomplete, or in any way inferior to what is intended by the drawings and this specification, and the same shall be immediately replaced at the contractor's expense.

15. **Painting, &c.**—All plates, bars, angles, and T irons are to be dipped in hot boiled linseed oil while they are at a temperature of about 200 degrees Fahrenheit immediately after they are taken from the rolls and sheared, and before they have suffered from the slightest exposure to the atmosphere or wet; and all the ironwork, before leaving the works, must have one coat of best anti-corrosive paint, and the bridge, after erection, shall be painted with three coats of good oil paint of a colour to be approved by the engineer, and the scroll work and mouldings of the cornice picked out in gold. The engineer may order any tests to be made of the quality of the paint that he may think fit, at the cost of the contractor.

16. **Quantities.**—The quantities given are not guaranteed, but great care has been taken in preparing them. The contractor must satisfy himself as to their correctness, as any inaccuracies cannot, when the contract has been entered into, be afterwards rectified.

17. **Weighing.**—The contractor will be required to weigh the whole of the iron work on an authorised public weighing machine in Salford, or other approved place, as the nett weight only will be allowed, and no additional weight will be paid for over and above that stated in the quantities, the correctness of which the contractor must satisfy himself before sending in his tender.

18. **Erection.**—The contractor shall carry on the work at such times and in such manner as not to interfere with the course of the river, and must observe and keep all the conditions and stipulations required by the provisions of the Salford Improvement Acts, or any Acts of Parliament incorporated therewith; and shall not infringe any rights of way or Navigation Bye-laws, or other privileges of the River Conservancy, or any lawfully-constituted authority, except at his own risk and damage.

19. The contractor will also be liable to make good any damage done to the works by floods or other accidents.

20. The contractor shall provide all necessary temporary fencing, and also efficient lights and watchmen, so as to prevent accidents both by day and night.

GENERAL CONDITIONS.

1. **Labour and Setting out.**—That the contractor shall provide all labour, machinery, tools, tackling, staging, scaffolding, water, and materials whatsoever (unless otherwise distinctly specified) which are or may become necessary to the full and complete execution of the several works in all their parts, although the same may not be particularly mentioned or described in this specification, or the several drawings accompanying the same; and he shall set out, and be responsible for the correct setting out of the several works, and for the accuracy of the dimensions and levels of every part of the same.

2. **Materials and Workmanship.**—That the whole of the works, as shown on the drawings, or described in this specification, or set forth by such drawings and instructions as may be given from time to time during the progress of the works, shall be executed by the contractor with

the best materials of their several kinds, and the most skilful workmanship, to the entire satisfaction of the engineer.

3. **Deviations.**—That no additions, deductions, alterations, or deviations, made in the works shall annul or invalidate the contract entered into by the contractor; but the value of such deviations, &c. (if any), shall be assessed by the engineer, and added to or deducted from the amount of the contract, as the case may be.

4. **Extras.**—That the engineer shall have full power and authority, from time to time, and at all times, to make and issue such further drawings, and to give such further instructions and directions as may appear to him necessary for the guidance of the contractor and the good and proper execution of the works, according to the specification; and the contractor shall receive, execute, and obey, and be bound by the same, as fully and effectually as though they had been mentioned or referred to in this specification; and the engineer may also alter, omit, vary, or only partially execute, any of the works contemplated by this specification and contract; but the corporation shall not become liable to the payment of any charges in respect of any such additions, omissions, or deviations, unless the instructions for the same shall have been given in writing by the engineer, nor unless the same shall have been claimed for by the contractor, in writing, within seven days after the week in which the same shall have been executed, such claim to contain the description and quantity of such work so done, the labour employed, and materials used therein.

It must be distinctly understood that the conditions of the specification are intended to be rigidly enforced, and especially that extra charges or claims in respect of extra work *will not be allowed* unless the works to which they relate are clearly without the spirit and meaning of the specification, nor unless such works are ordered in writing, in the prescribed manner, and at the prescribed time, the intention being that the works to be performed shall be *fully* and *completely* executed for the amount set forth in the accepted tender, to the end that the corporation shall become informed of the extent (as nearly as may be) of their pecuniary liability under this contract. Verbal instructions

and instructions given otherwise than as provided for in this specification are not to be deemed instructions for the proper execution of the works *not involving* extra charges.

5. **Nett Measurements.**—That all measurements, whether on behalf of the contractor or the corporation, shall be so made and taken as to express only the actual nett quantity in work, notwithstanding any contrary custom or practice whatsoever.

6. **Full Work.**—That the several works in every branch, when finished, shall be in all their parts of the full dimensions expressed or implied by this specification, and the drawings therein referred to, any local or other custom to the contrary notwithstanding.

7. **Care and Risk of Work.**—That from the commencement to the completion of the works, and until the same shall have been formally delivered over to the corporation, the care and risk of the same shall be entirely with the contractor, who shall defray all damages, costs, charges, and expenses occasioned by or consequent on the acts or omissions of himself, his agents, servants, or workmen, or arising by reason of the execution of the works contemplated by the specification, whether the same shall happen to the property of the corporation, or to that of any other person or persons, and shall hold the corporation harmless in respect thereto; and in case the corporation shall pay, or be liable to pay, any sum or sums of money in discharge of any such damages and expenses, they shall be at liberty to deduct the same from the amount from time to time, or at any time due or accruing to the said contractor, or to recover the same from him by action at law, or otherwise, as they may be advised.

8. **Rejected Work or Materials.**—That the engineer shall have full liberty, from time to time, and at all times, to inspect the materials and workmanship employed in and about the works hereby contracted for, and may at any such time reject any of the materials or workmanship furnished by the contractor which may appear to him to be defective, unfit, or improper for the several purposes to which they have been or are intended to be applied, or are not in accordance with the description mentioned in or intended by this specification, or the drawings, instructions,

and directions respectively, and that the contractor shall forthwith remove all such materials and workmanship so rejected, when required to do so by the engineer, and shall remove and carry away the same from the works and lands of the corporation, and shall replace the same with such better and more efficient quality and description of materials and workmanship as shall be satisfactory to the engineer; and in case the contractor shall neglect or refuse to comply with the foregoing conditions it shall be lawful for the engineer, on behalf of the corporation, by his agents, servants, and workmen, to remove the materials and workmanship so rejected, or any part thereof, and to replace the same with such other materials and workmanship as may be satisfactory to him; and the corporation may, on the certificate of the engineer, deduct the expenses incurred thereby, or to which the corporation may thereby be put or be liable, or which may be incident thereto, from the amount of any money which may be or become due to the contractor, or to recover the same by action at law from him, as the corporation may determine.

9. **Sub-letting.**—That the contractor shall not assign his contract, or any part thereof, or underlet the same, or make any sub-contract with any other person or persons for the execution of any portions of the works without the consent in writing of the engineer.

10. **Foreman.**—That the contractor shall give all necessary personal superintendence during the execution of the works, and shall constantly employ thereon one good and competent foreman, careful and skilled in the trades and callings required by this specification, to manage and direct in the absence of the contractor; and such foreman shall, on behalf of the contractor, receive and have charge of such drawings, specifications, and documents, as may be furnished for the guidance and use of the contractor, and shall also receive and obey all such instructions as may be given by, and shall not be changed without the consent of the engineer, but may be objected to and dismissed by him; and thereupon the contractor shall forthwith employ another good and competent foreman in his stead, and so on from time to time, and as often as the engineer shall require.

11. **Workmen.**—That in like manner the contractor shall employ, in and about the execution of the several works, only such foreman, agents, and workmen, as are careful and skilled in their various trades and callings; and the engineer shall have full power to object to and dismiss any person employed by the contractor in or about the works who shall, in his opinion, misconduct himself, or be incompetent for the due and proper performance of his duties.

12. **Control over Works.**—That the several works shall from time to time, and in such orders and portions as shall be directed, be commenced and carried on with due diligence, and as much expedition as the engineer may require; and in case the contractor shall fail to do so, or shall neglect to provide to the satisfaction of the engineer an adequate supply of proper materials, or a sufficient number of qualified workmen to execute the works with the diligence required, then the engineer shall be at liberty to employ other contractors or workmen in and about the said works, and to provide the necessary materials, and the corporation may charge the cost thereof to the account of the contractor, and deduct the same from any moneys due or to become due to the contractor, or recover the same by action at law or otherwise, as they may be advised, and that the contractor shall, without recompense, claim, or demand, delay or suspend the progress of the works, or any part thereof, whenever and for such time as he shall be required by the engineer, and the contractor shall, whenever directed by the engineer, and upon all other needful occasions, at his own expense, properly cover and protect such of the works as may be liable to sustain injury from weather or otherwise.

13. **Bankruptcy of Contractor.**—That it shall be lawful for the corporation, in case the contractor shall fail in the due performance of any part of his undertaking, or shall become bankrupt or insolvent, or shall compound with his creditors, or propose any composition to his creditors for the settlement of his debts, or shall carry on, or propose to carry on, his business under inspectors on behalf of his creditors, or shall commit any act of bankruptcy, or shall not, according to the judgment of the engineer, exer-

cise such due diligence and make such due progress as would enable the works to be completed within the time hereinafter mentioned, to determine the contract as far as respects its performance by the contractor, by a notice to that effect in writing (but without thereby affecting the obligations and liabilities of the contractor, the whole of which shall continue in force as fully as if the contract had not been so determined, and as if the works subsequently executed had been executed by or on behalf of the contractor, and also without thereby creating any trust in his favour), and may enter upon and take possession of the works, and of all the plant, tools, and materials of the contractor, and use and sell the same as the absolute property of the corporation, and may proceed to complete the works, either by contract or otherwise, by engaging workmen and providing materials and implements, and may deduct the cost thereof from any sum or sums of money due or to become due to the contractor in respect of the contract, or recover the same by action at law, or otherwise, as the corporation may be advised.

14. **Disputes.**—That any disputes which may arise during the progress of the works, or at or after their completion, whether as to the meaning of this specification, or the materials, workmanship, or any other matters whatsoever relating to this contract, shall be referred to the engineer, whose decision shall be final, conclusive, and binding, both on the corporation and the contractor.

15. **Tenders.**—Contractors must send in tenders according to the annexed form, and schedule of quantities, filling up all the blanks, as no other will be accepted.

The contractor must make copies or tracings of all drawings required for carrying out the works at his own expense.

16. **Payments.**—That the contractor shall be entitled to payment for his work in manner following, that is to say: When work to the value of not less than one thousand pounds has been completed, 90 per cent. of the amount shall be paid within one week after the engineer has certified to that effect to the corporation, and so by instalments of not less amount until the work is finished. The balance retained in hand shall be paid at the end of six months from the date of the borough engineer's last certi-

ficate, provided the engineer shall then certify that the work is in a state of sound repair, to his satisfaction, but not otherwise.

17. **Completion of Works under Penalties.**—That the contractor shall complete the whole of the works before the day of , on which day he shall deliver up the works in a complete and perfect state, and to the entire satisfaction of the engineer of the corporation. And in case the contractor shall fail in the due performance of his contract, by and at the time hereinbefore mentioned, he shall be liable to pay to the corporation, as and for liquidated damages, the sum of £20 (twenty pounds) for each and every week within the appointed and actual time of completion and delivery hereinbefore mentioned, and the corporation may deduct the same from any moneys in their hands due or to become due to the contractor.

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